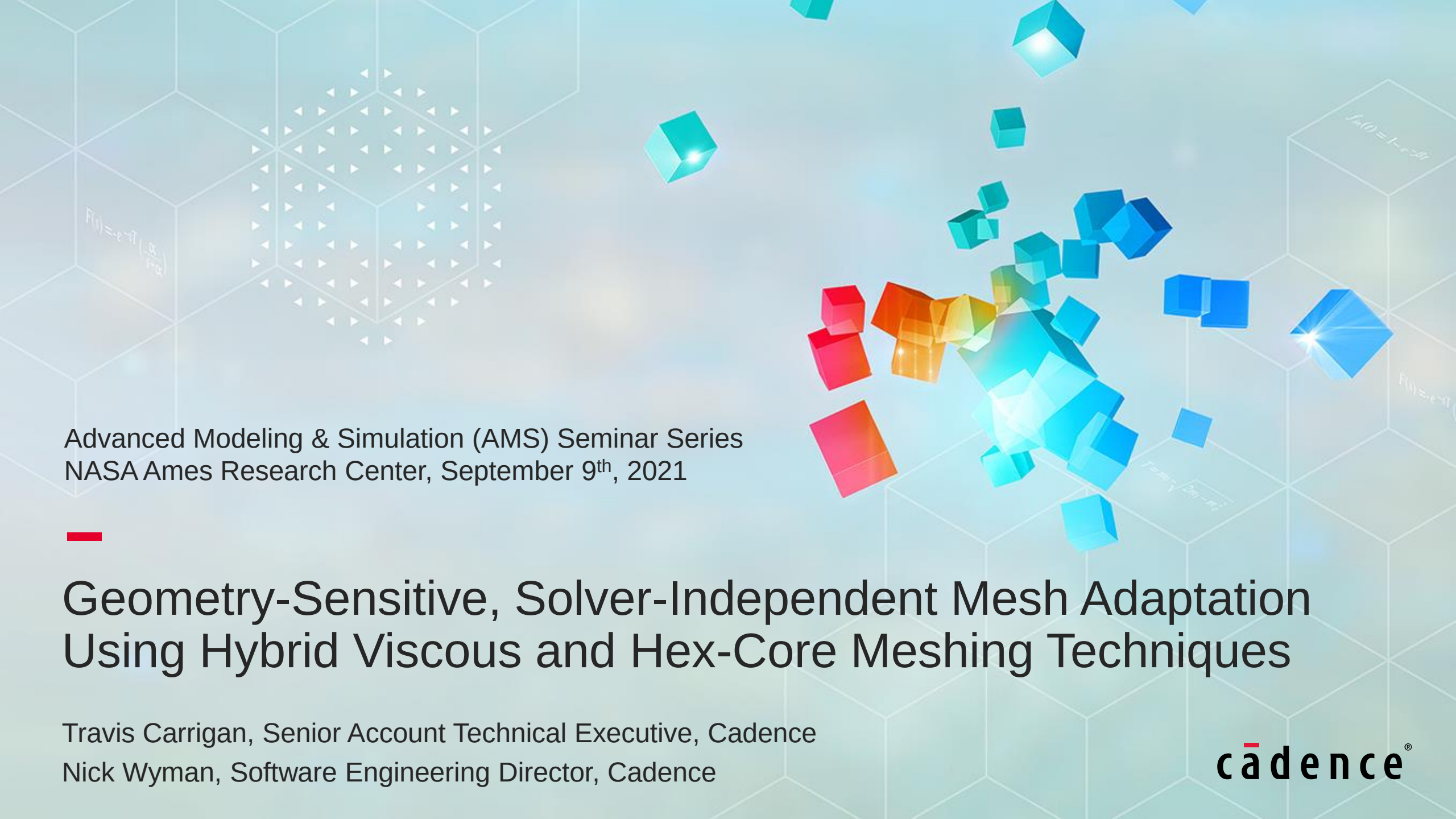


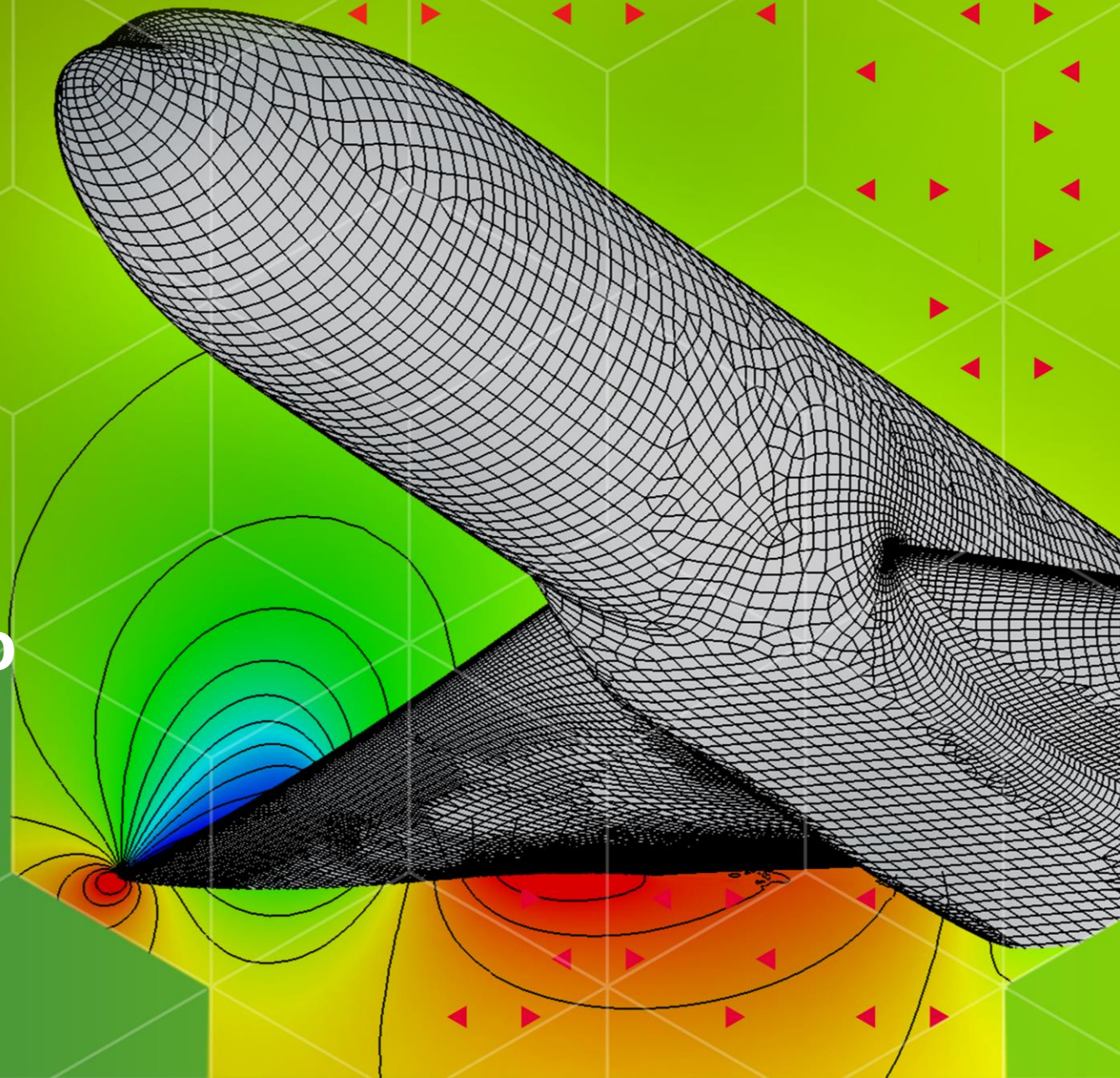
Advanced Modeling & Simulation (AMS) Seminar Series
NASA Ames Research Center, September 9th, 2021

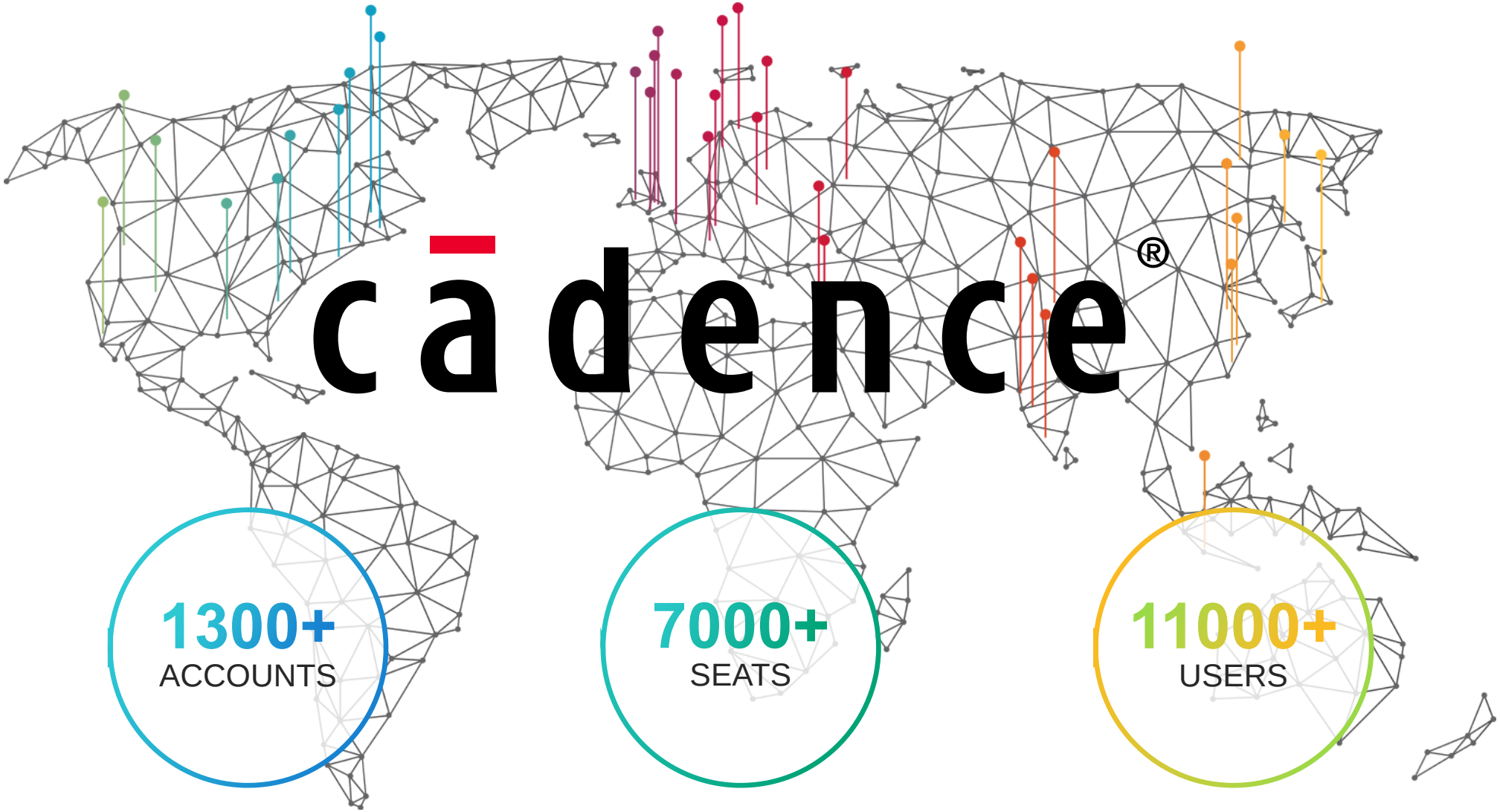
Geometry-Sensitive, Solver-Independent Mesh Adaptation Using Hybrid Viscous and Hex-Core Meshing Techniques

Travis Carrigan, Senior Account Technical Executive, Cadence
Nick Wyman, Software Engineering Director, Cadence

cadence®

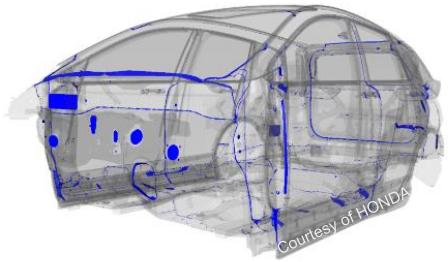
“A single engineer/scientist must be able to conceive, create, analyze, and interpret a large ensemble of related simulations in a time-critical period, without individually managing each simulation, to a pre-specified level of accuracy.” – CFD Vision 2030 Study





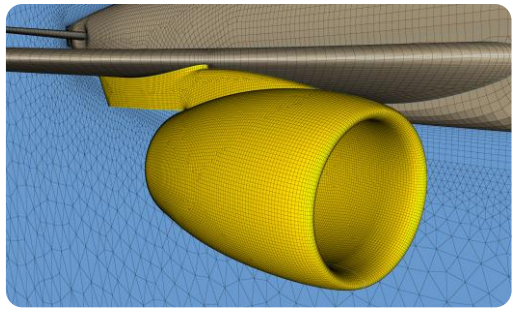
Technology and Solutions

Multi-disciplinary simulation you can trust



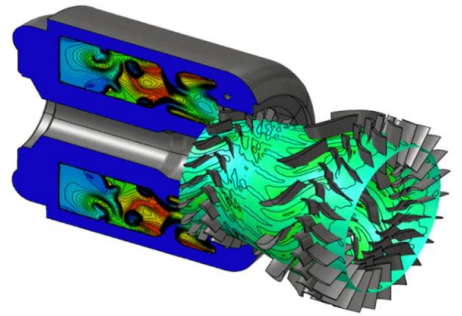
GEOMETRY PREPARATION

- Native CAD import
- Geometry creation, manipulation, and repair
- Tolerance-based healing and sealing



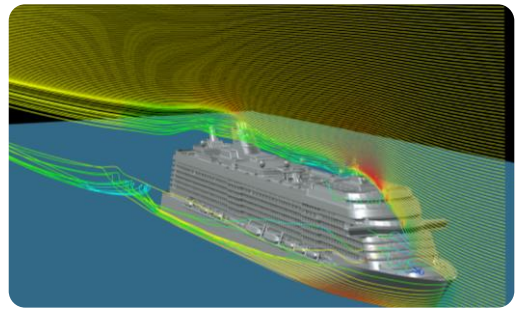
MESH GENERATION

- Multiblock structured
- Volume-to-surface unstructured
- Surface-to-volume unstructured
- Adaptation and high-order
- Parallel mesh generation



SIMULATION

- Density and pressure-based unstructured finite-volume solvers
- Block-structured solver for rotating machinery
- Combustion, fluid-structure interaction, free-surface modeling, and cavitation



ANALYSIS AND OPTIMIZATION

- Postprocessing of mesh and solution data
- Multi-disciplinary design optimization
- Sensitivity analysis and uncertainty quantification

From CAD to Analysis, and Everything in Between

Solutions Portfolio

The flexibility you've been looking for

Connect to third-party and in-house meshers and solvers

Plugin API

OMNIS™ Environment

Multidisciplinary simulation platform

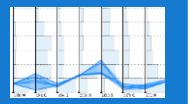
Design · Optimize · Solve · Mesh · Geometry

OMNIS/Agile

Rotating machinery design

FINE/Design3D

Multidisciplinary and robust optimization



OMNIS/Autoseal

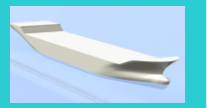
Automated geometry sealing tool

OMNIS CAD tools

Geometry create and repair tools

FINE/Marine

Marine, Offshore & Free-surface

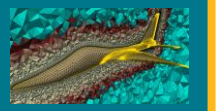


OMNIS/Mpacts

Discrete Element Method

Pointwise®

Structured, unstructured, high-order, and adaptive meshing

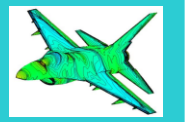


OMNIS/Hexpress

Unstructured meshing

OMNIS/Open-DBS w/ OpenLabs™

Aero, Multiphysics and Combustion

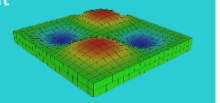


OMNIS/Turbo

Rotating machinery simulation

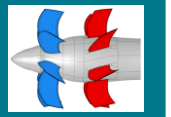
OMNIS/Oofelie

Finite Element Analysis



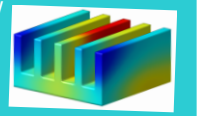
OMNIS/Autogrid

Multiblock structured meshing



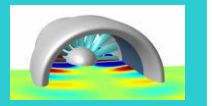
OMNIS/Open-PBS

Low-speed flow and conjugate heat transfer



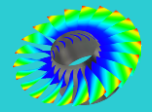
OMNIS/Acoustics

Aero- and Vibro-acoustics



FINE/FSI-Oofelie

Fluid-structure interaction



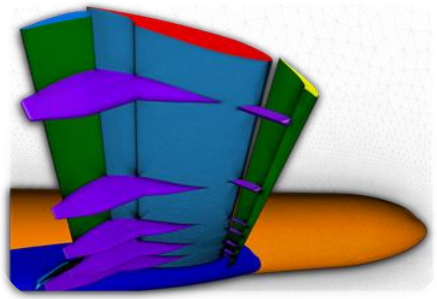
“The powerful meshing capability that Pointwise provides has been a great asset to our team. In addition, its **flexibility** has made **integration** with the rest of our tools remarkably easy.”

Tim MacDonald
Co-founder and CTO, Exosonic, Inc.

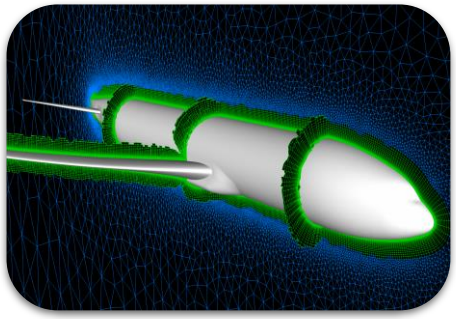
“Pointwise's bottom-up meshing methodology inherently gives the user greater **control** over the surface, capturing its details, eliminating the post-meshing anomalies that result from using a top-down meshing methodology, saving a great amount of time (and frustration).”

Matthew Graczyk
CEO, PteroDynamics

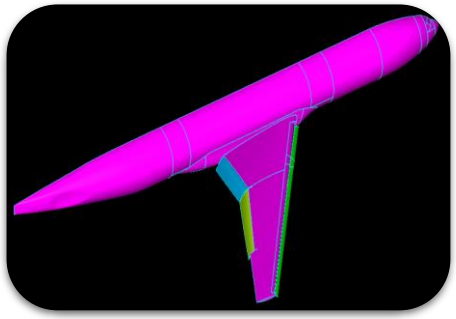
Workshop and Benchmark Participation



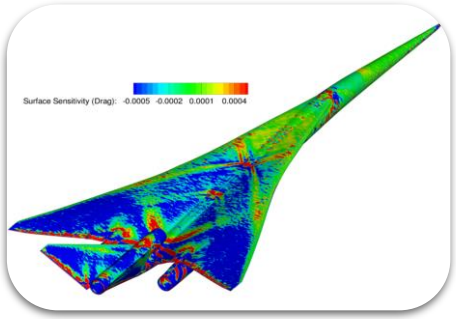
AIAA High-Lift Prediction



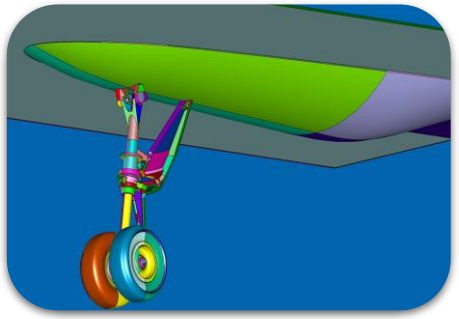
AIAA Drag Prediction



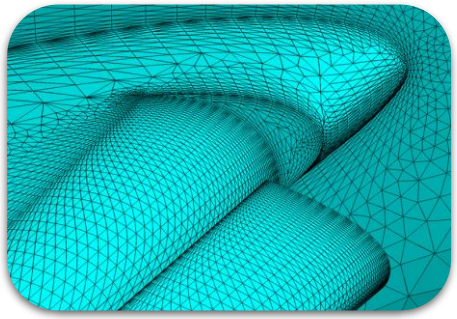
AIAA Geometry and Mesh Generation



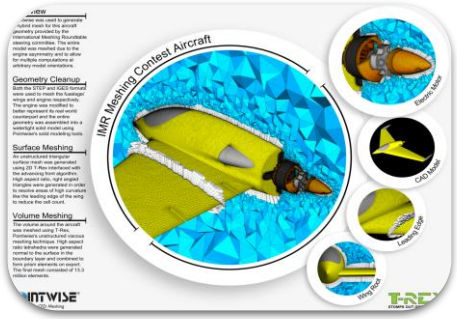
AIAA Sonic Boom Prediction



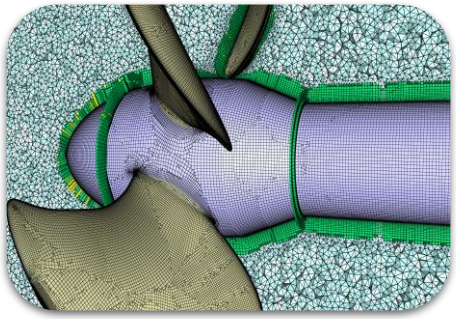
AIAA Airframe Noise Computations



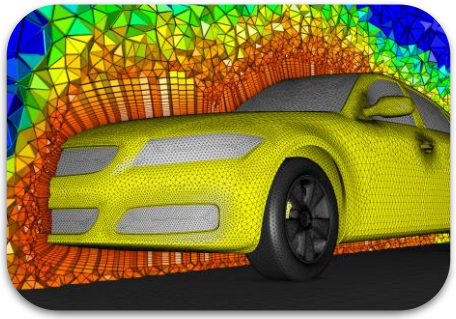
High-Order CFD Methods



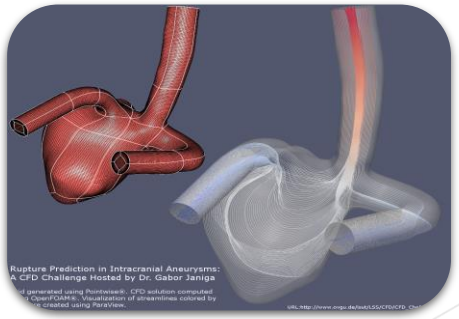
International Meshing Roundtable



Potsdam Propeller Test Case

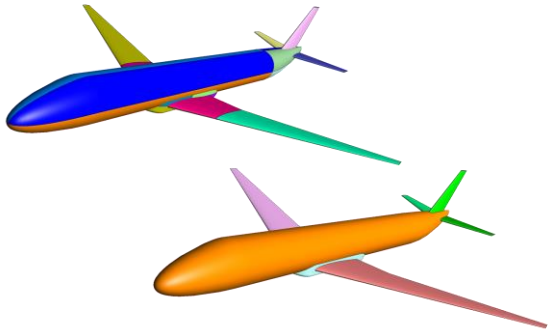


DrivAer

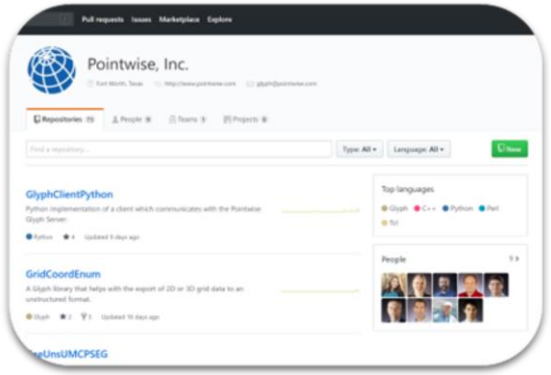


Intracranial Aneurysms

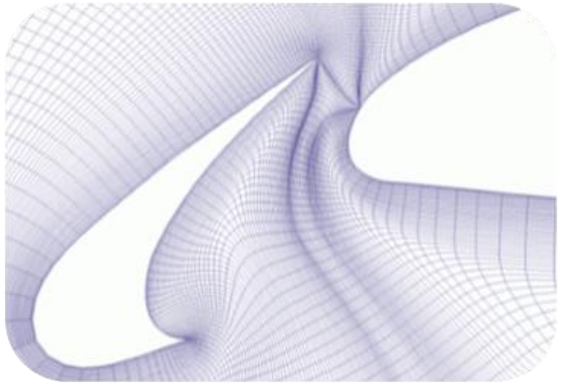
Pointwise Product and Technology



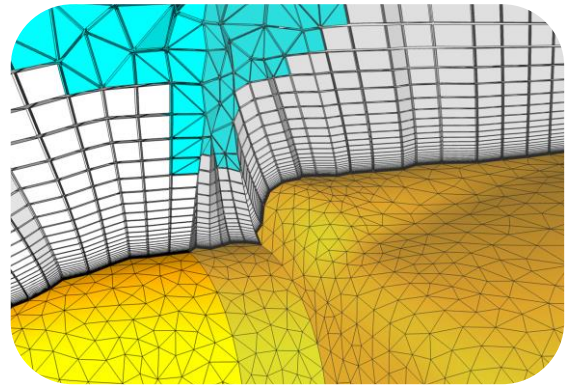
Geometry



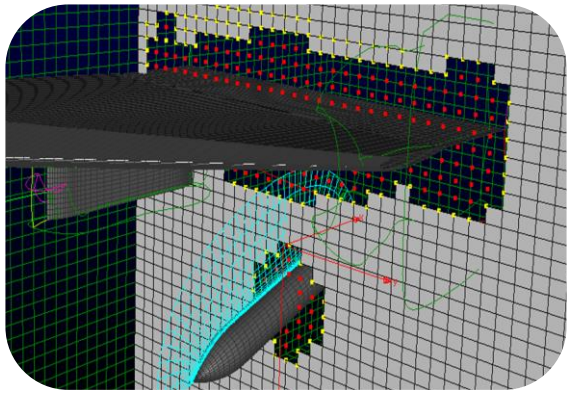
Plugins



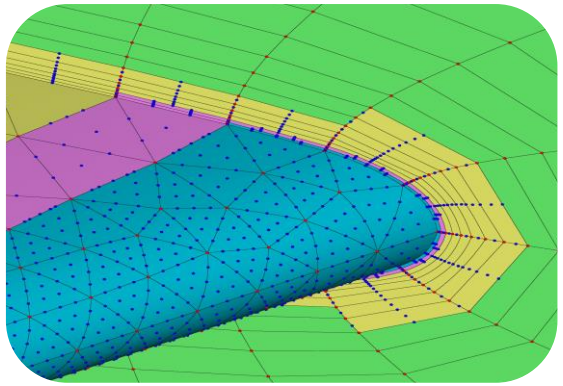
Structured



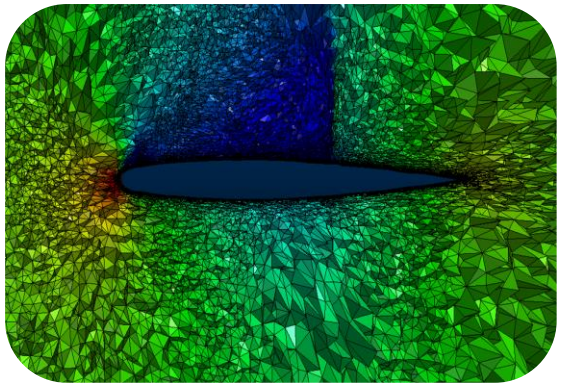
Hybrid



Overset



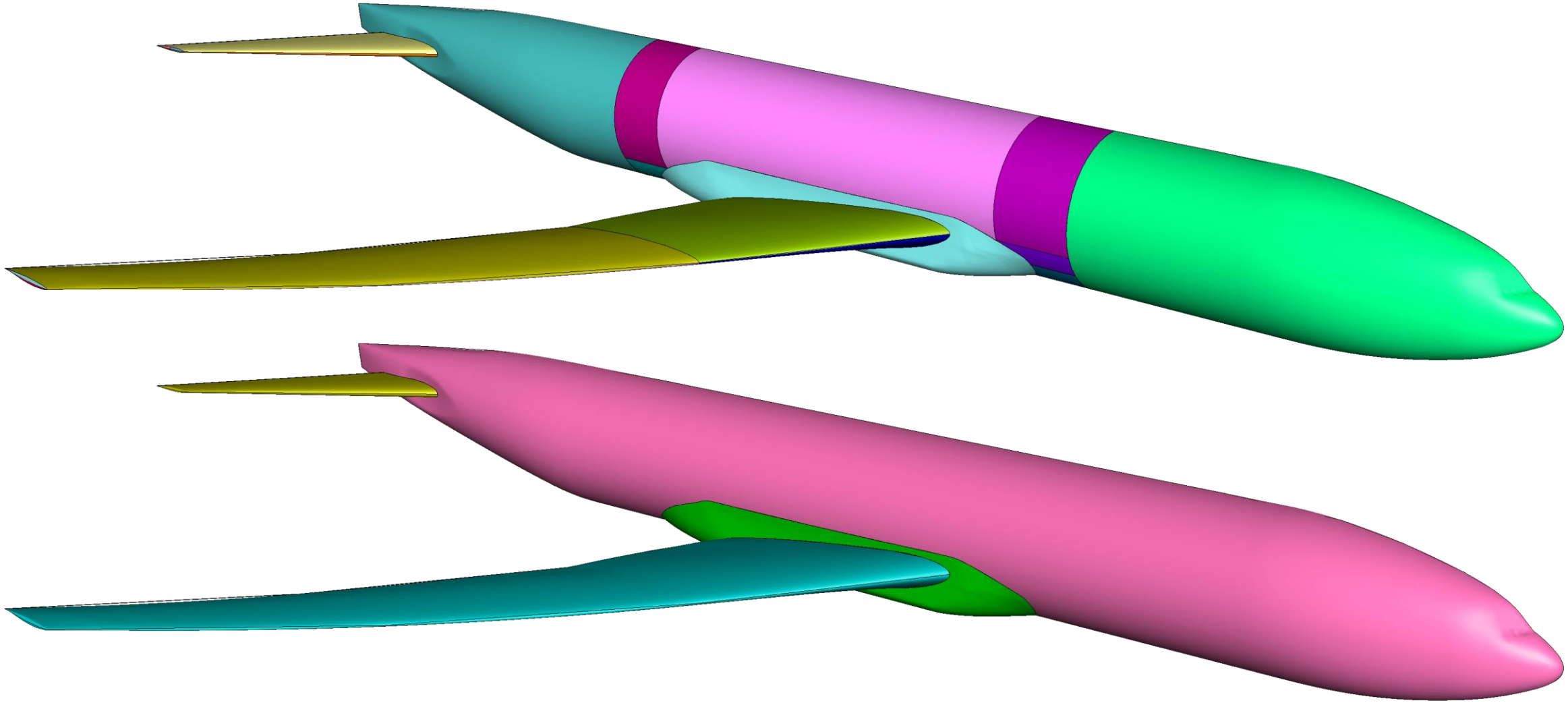
High-Order

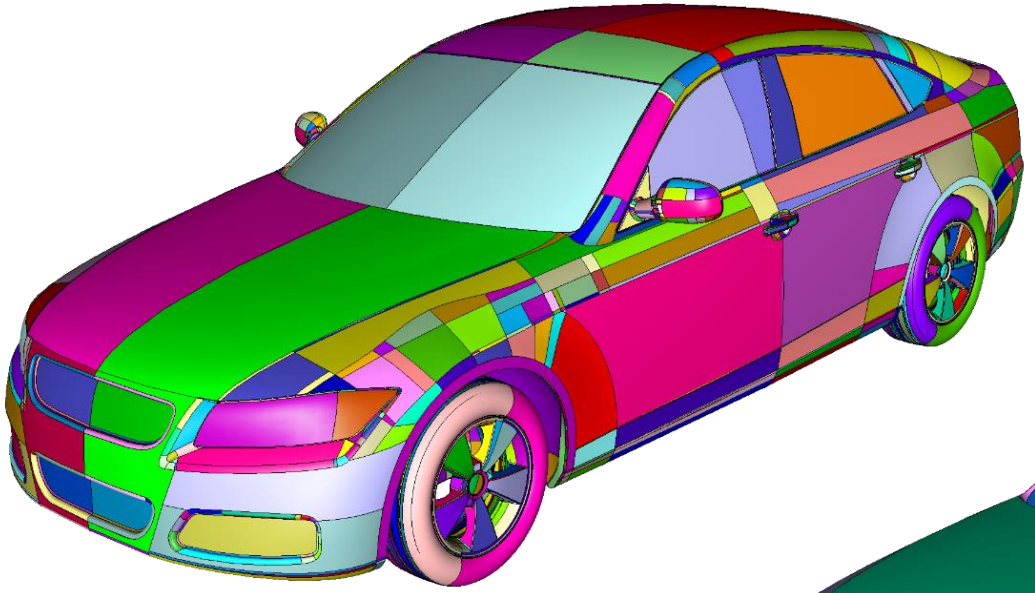


Adaptation

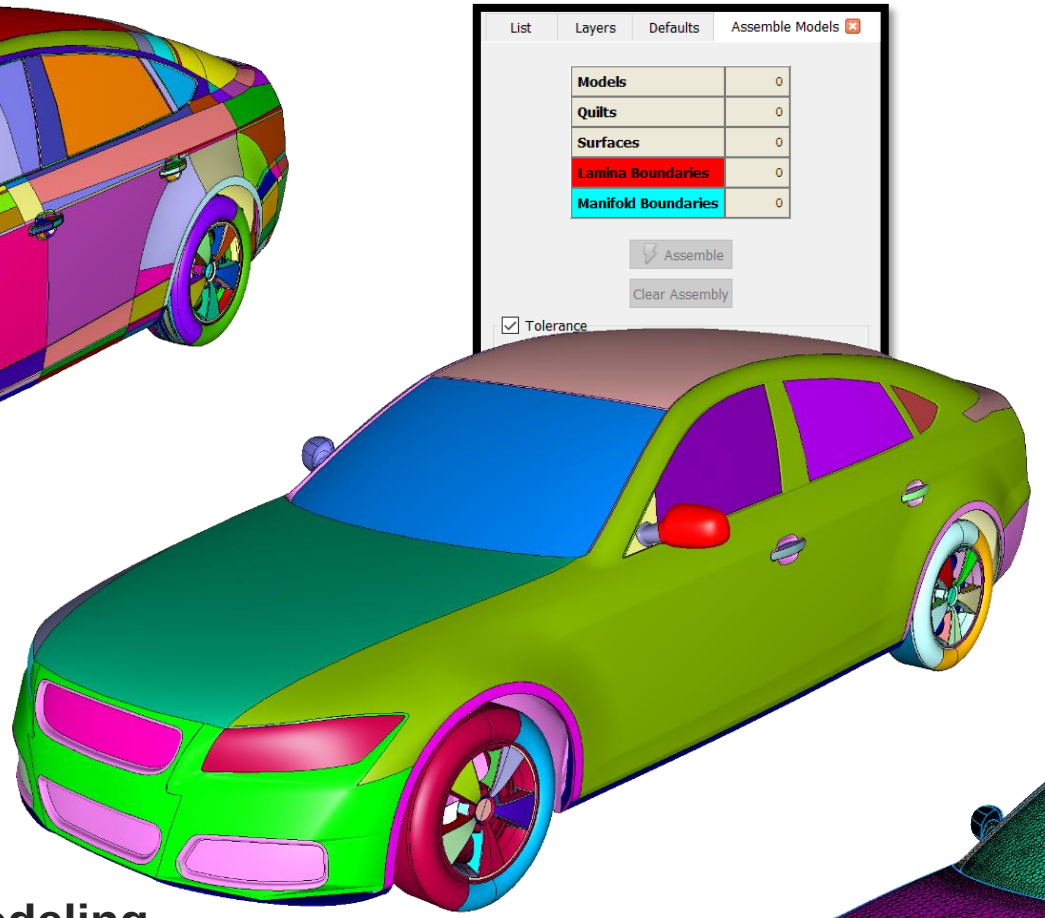
Automation

Flashpoint

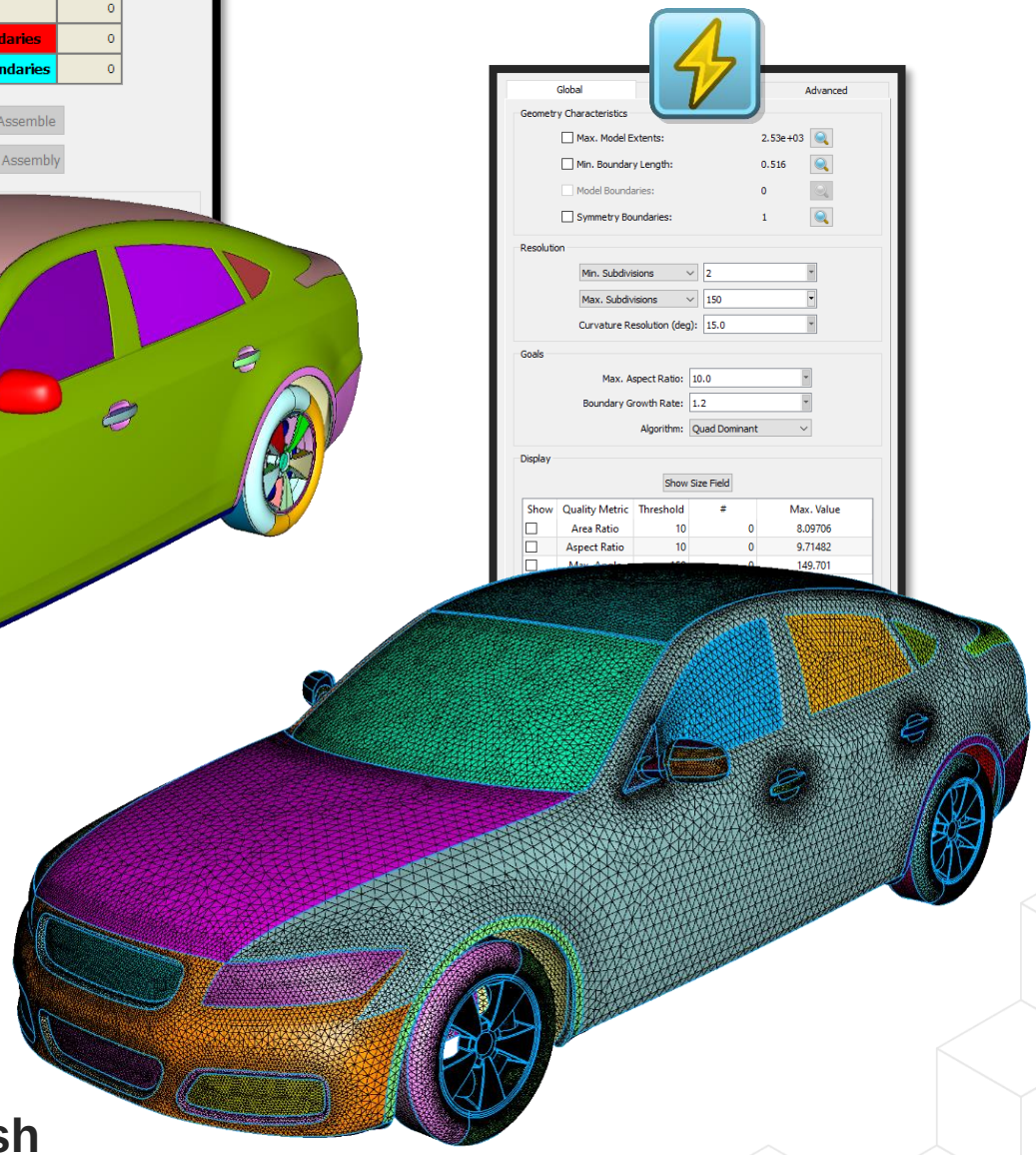




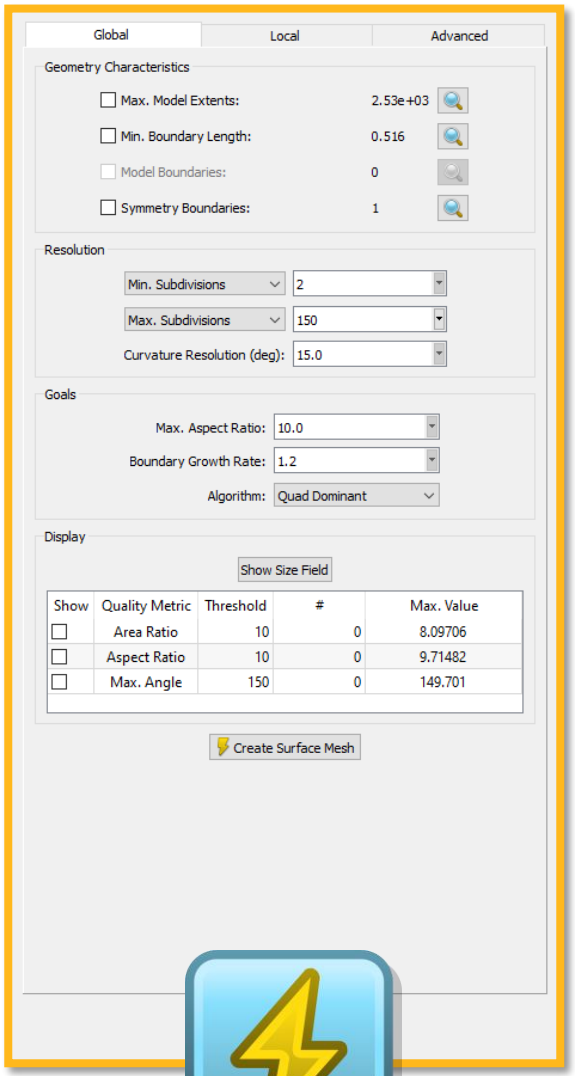
CAD Model
15,000 Surfaces

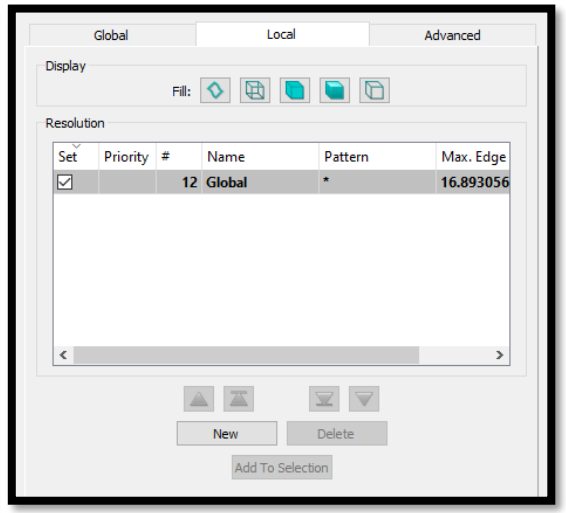


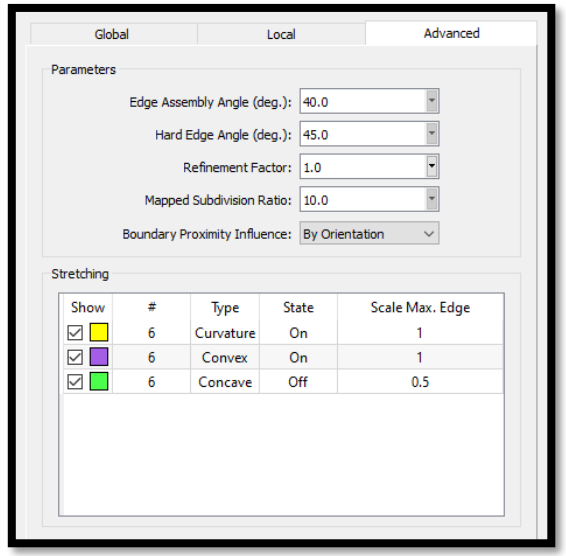
Solid Modeling
7 Watertight Models
400 Quilts

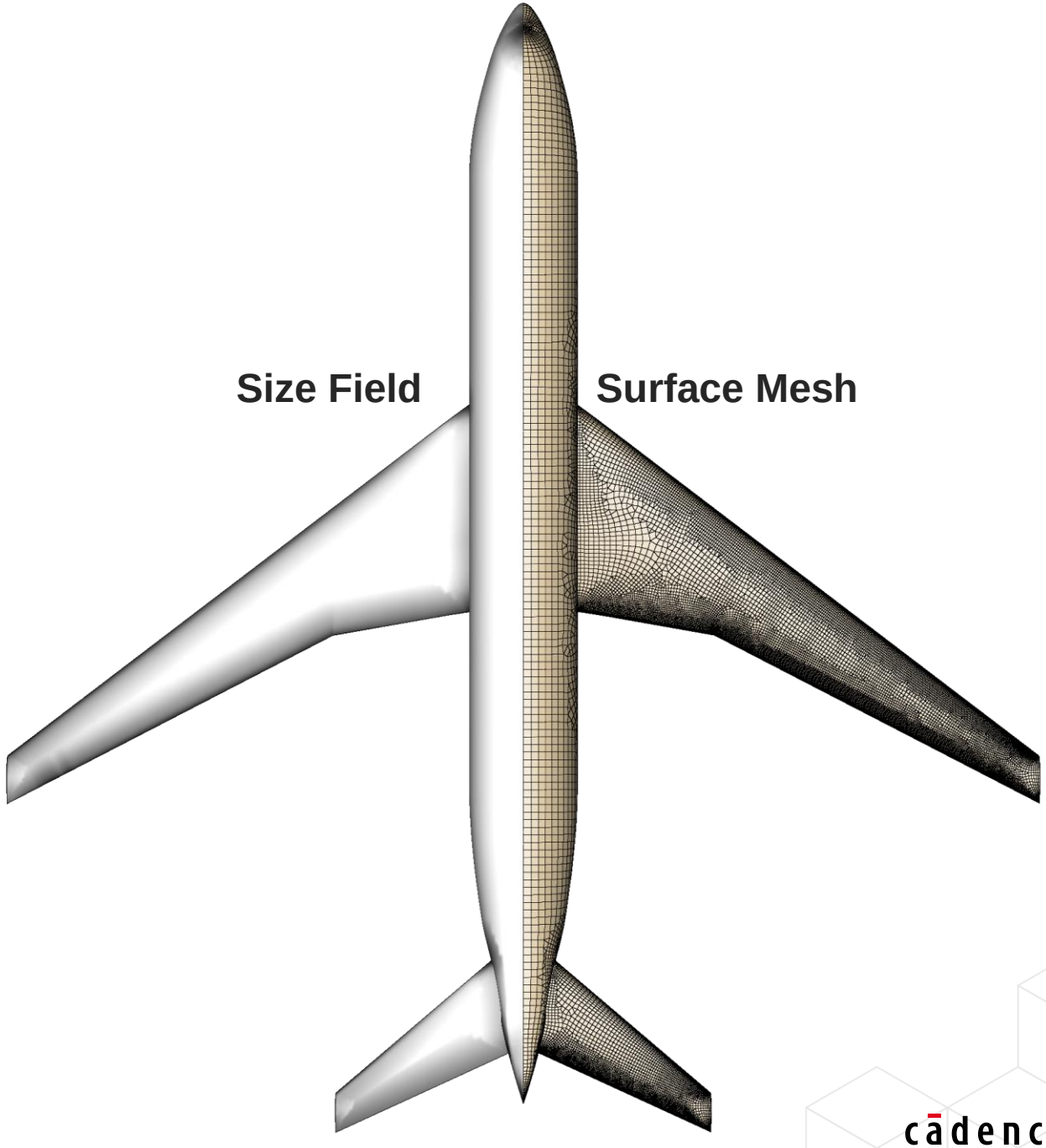


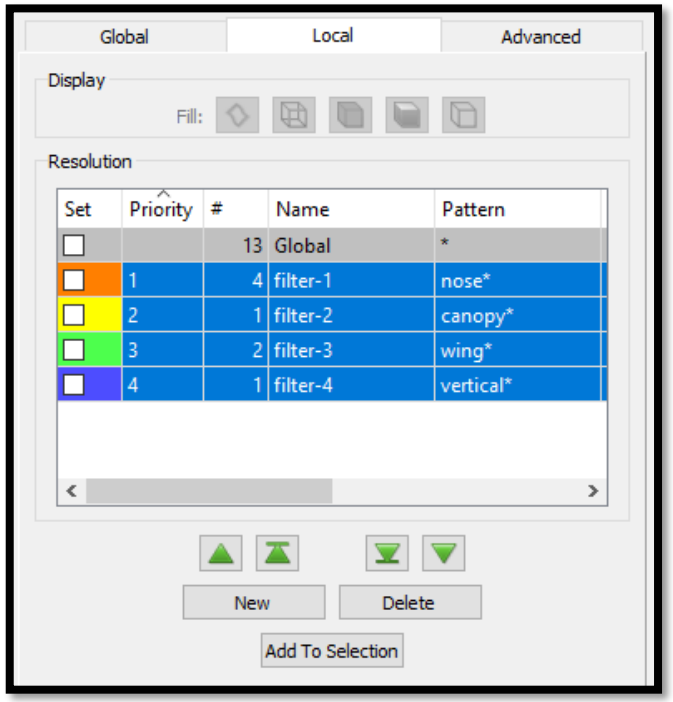
Surface Mesh
Automatically Watertight

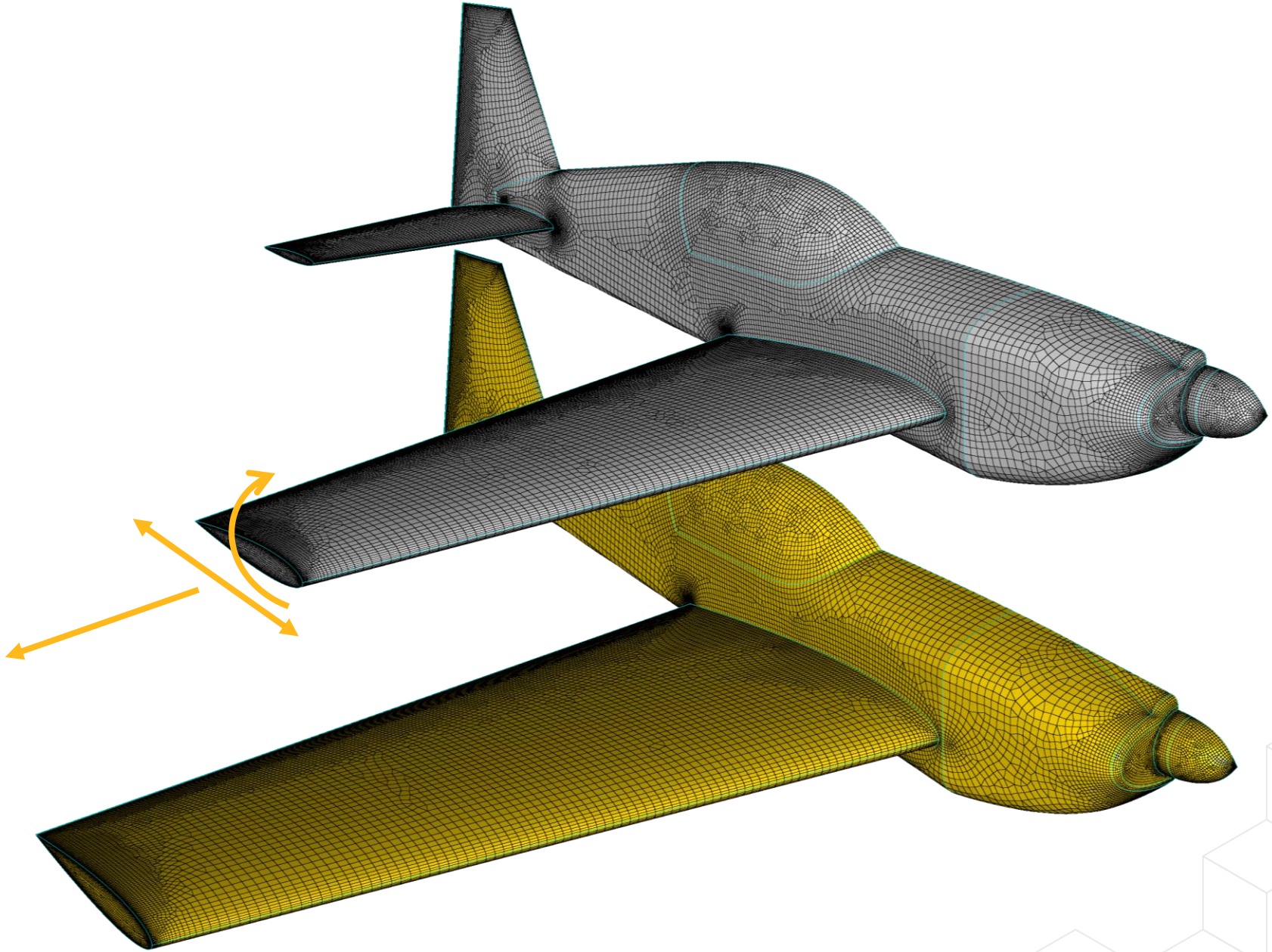


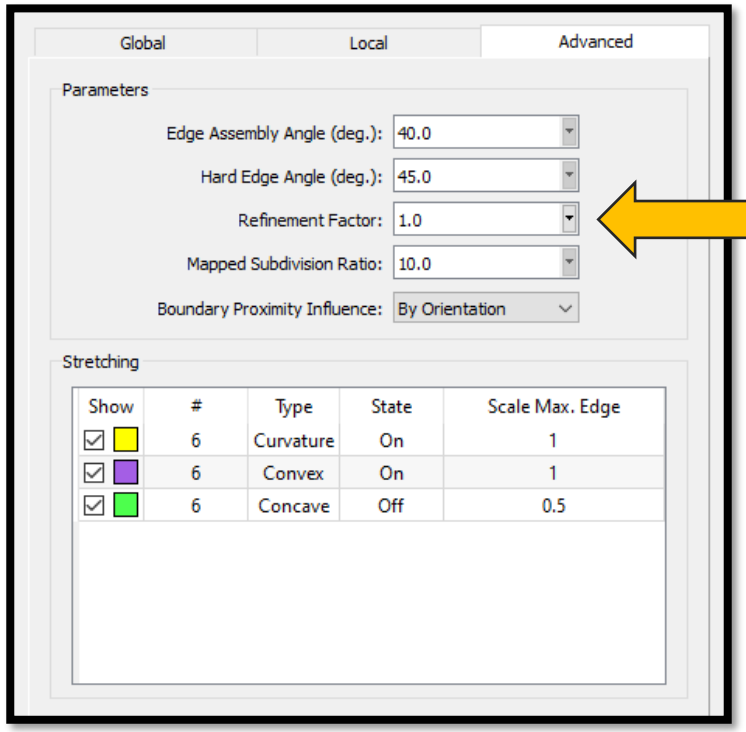


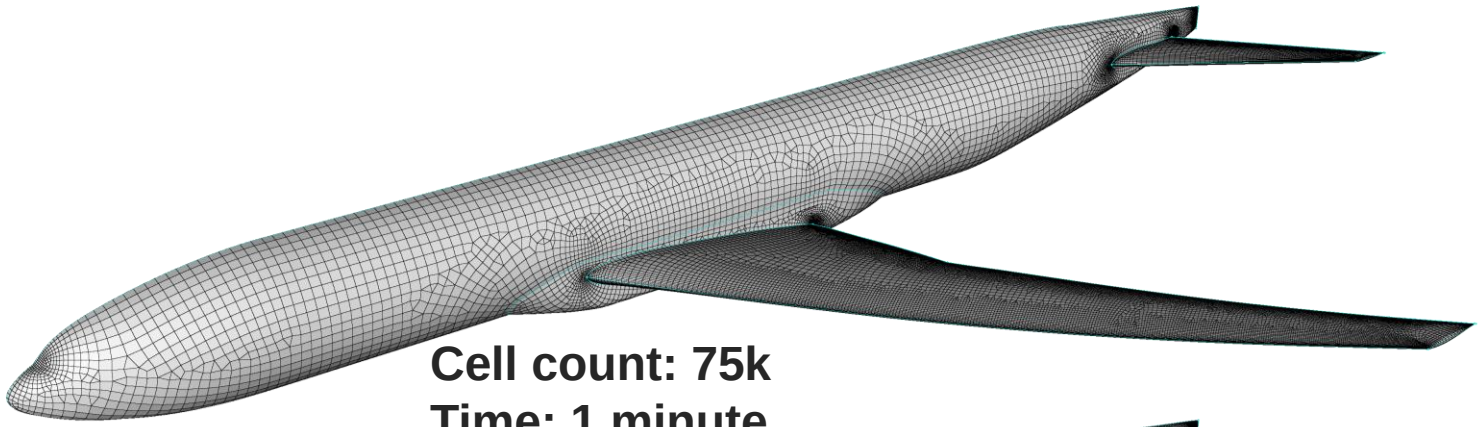




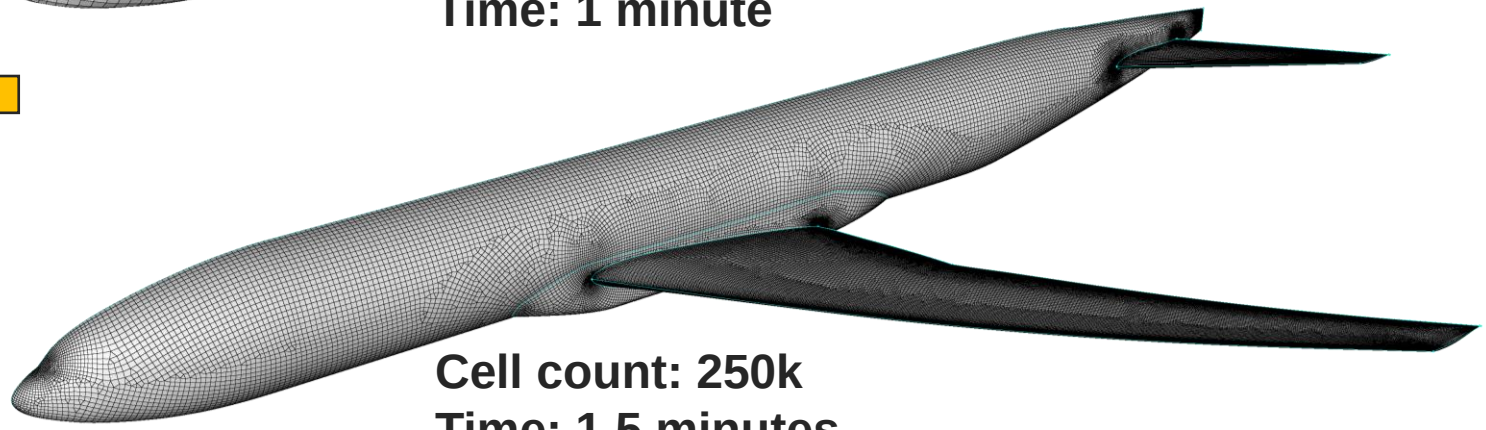




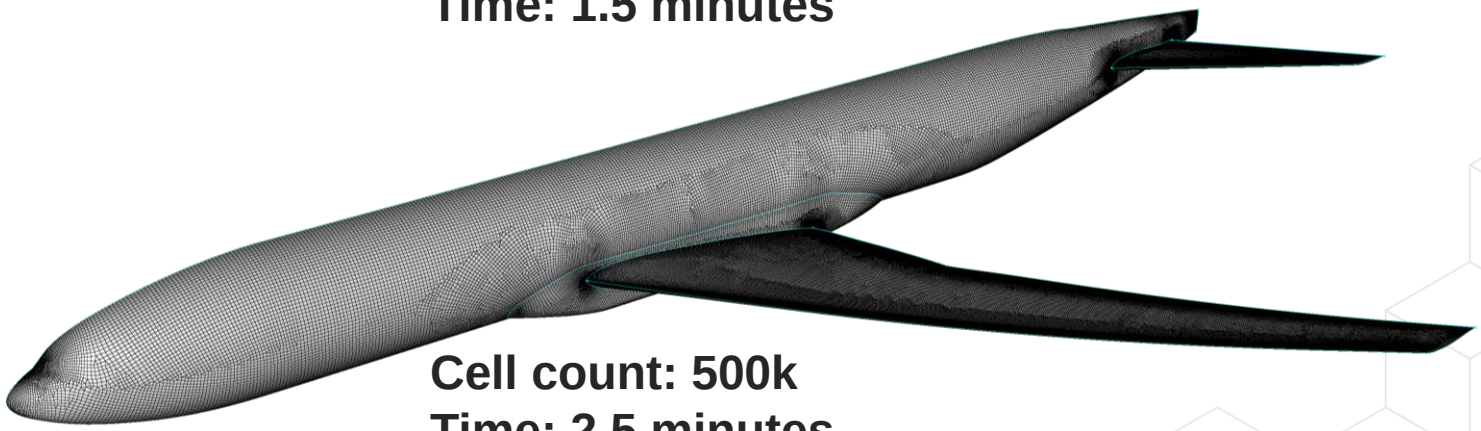




Cell count: 75k
Time: 1 minute

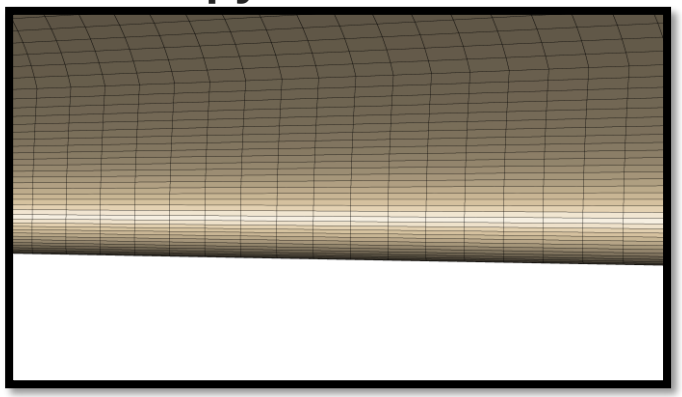


Cell count: 250k
Time: 1.5 minutes

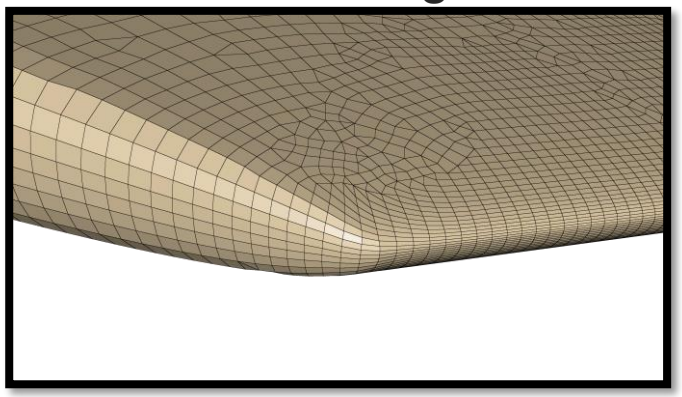


Cell count: 500k
Time: 2.5 minutes

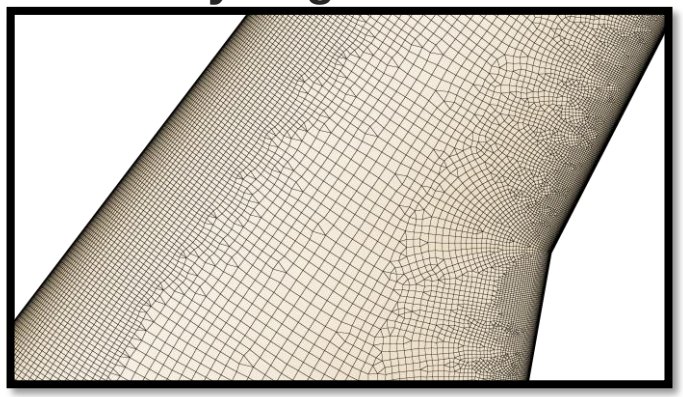
Anisotropy



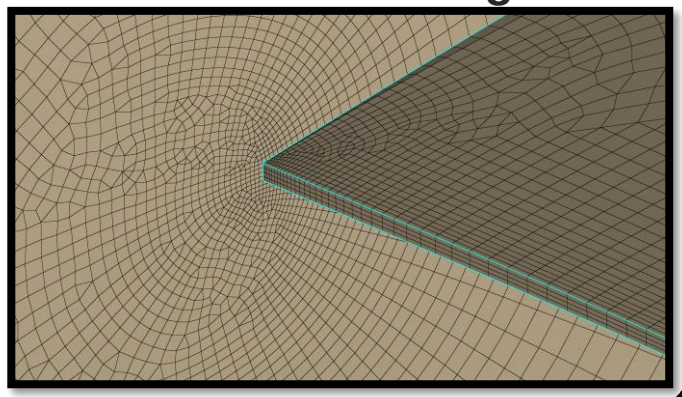
Curvature Blending

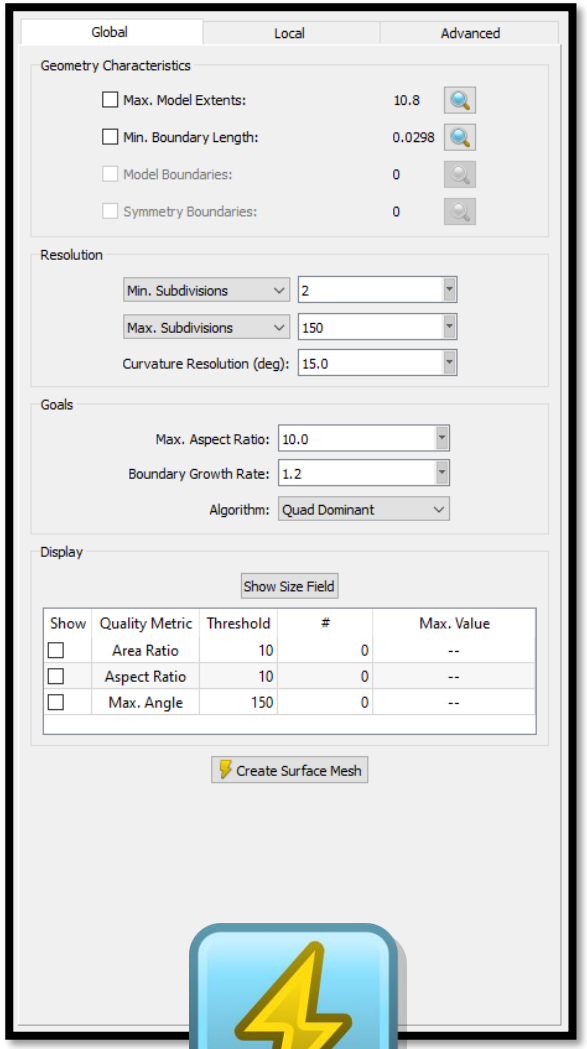


Boundary Alignment

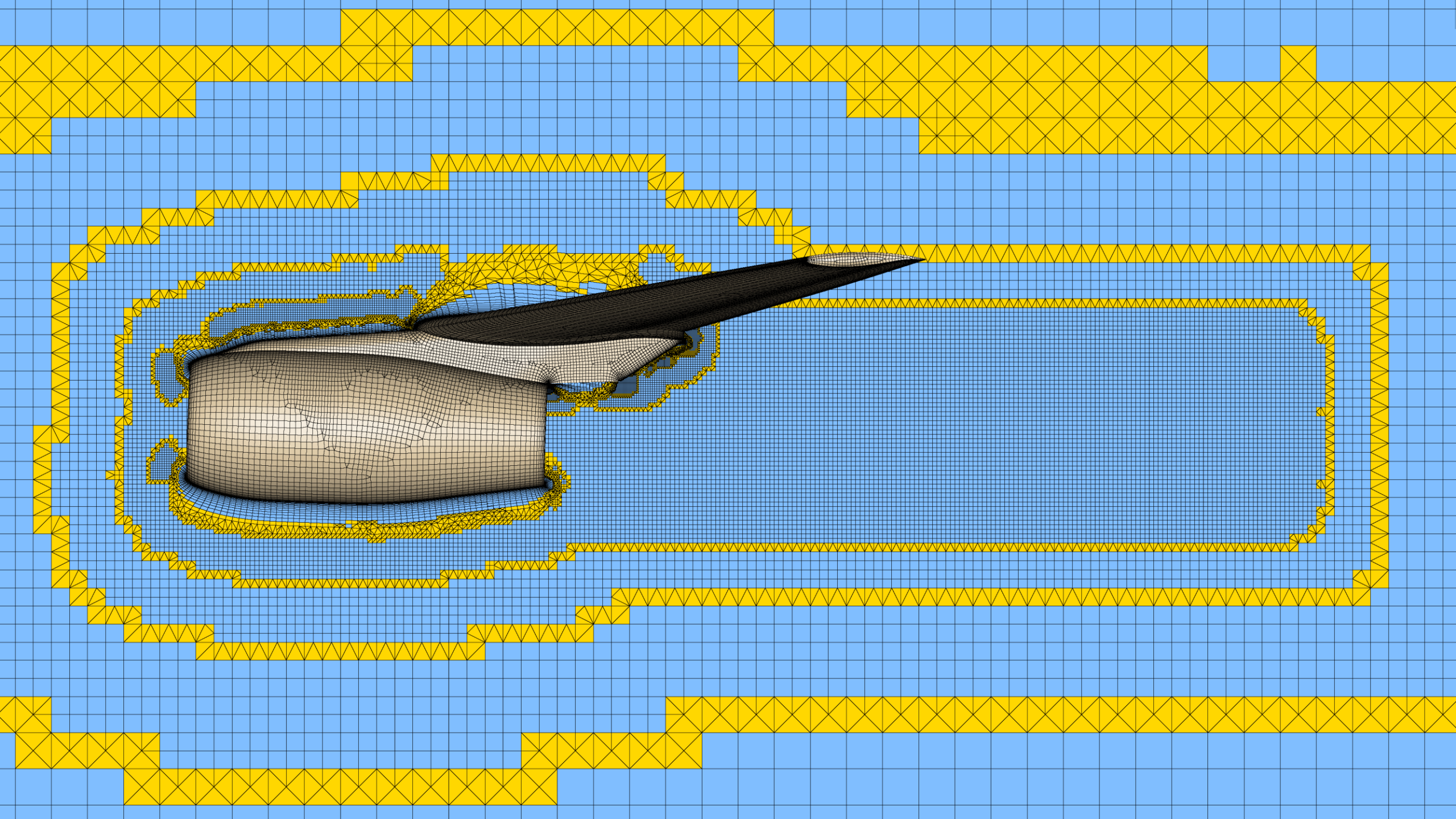


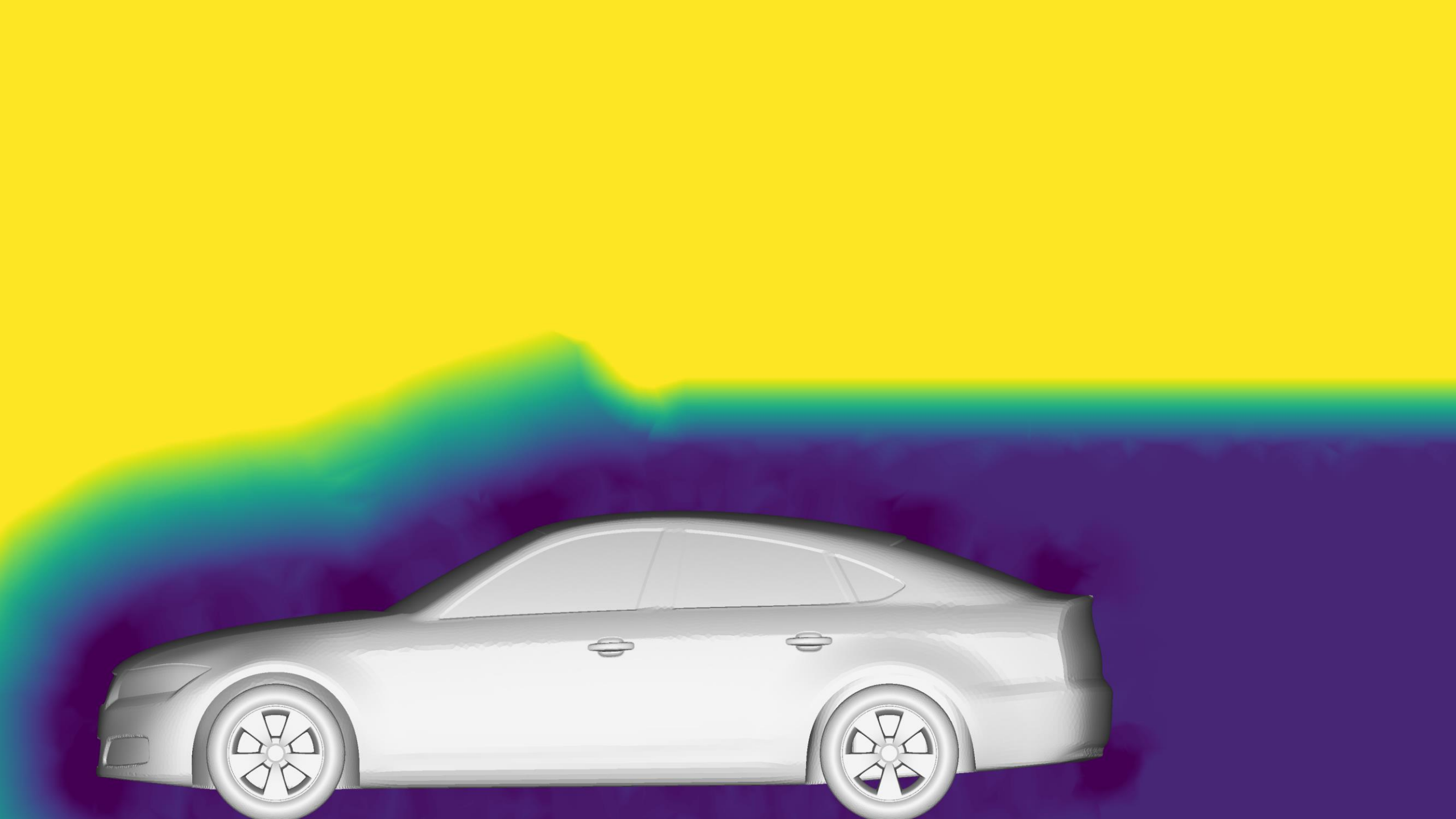
Thin Feature Handling

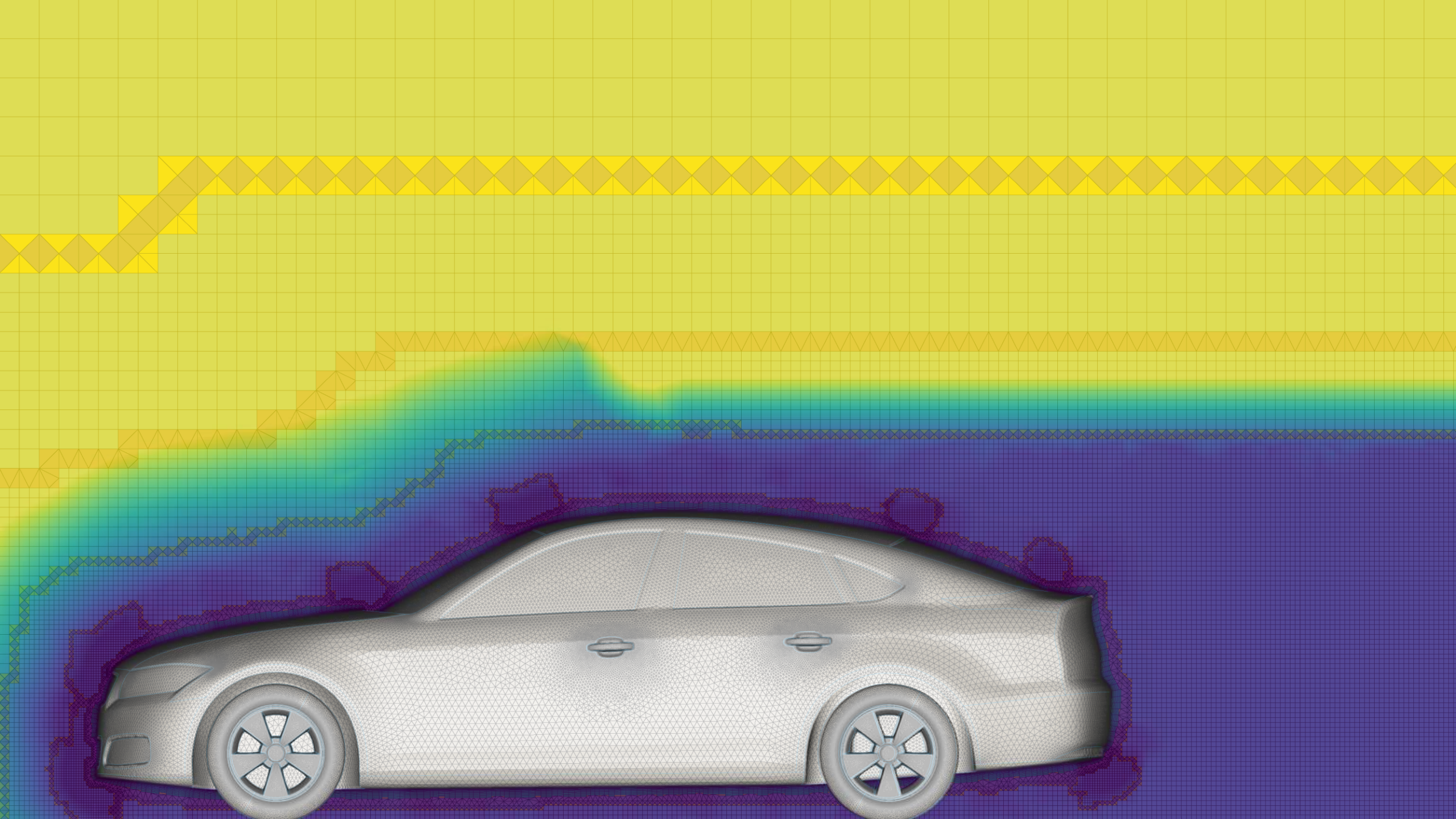


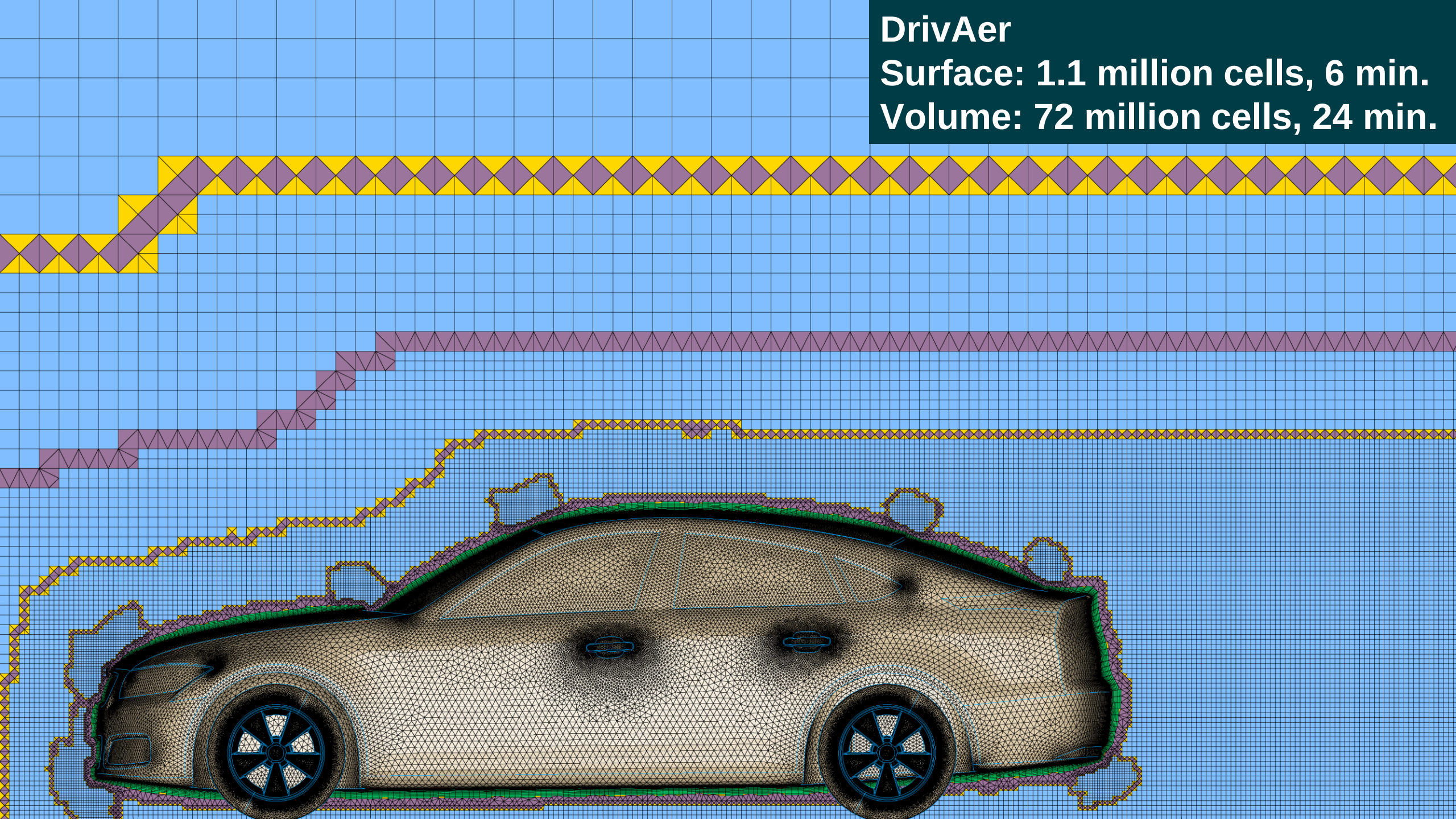


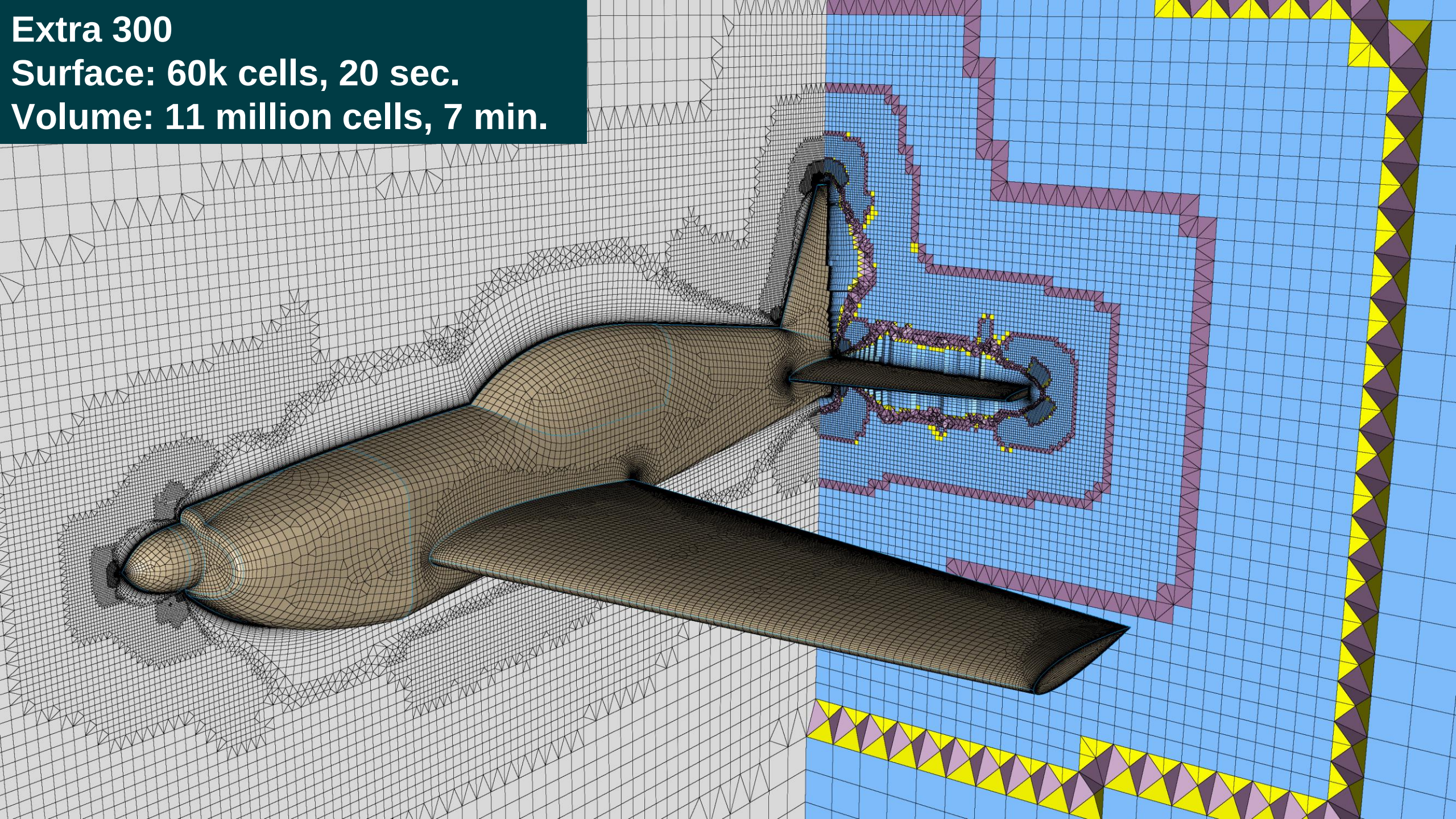
Voxel Meshing

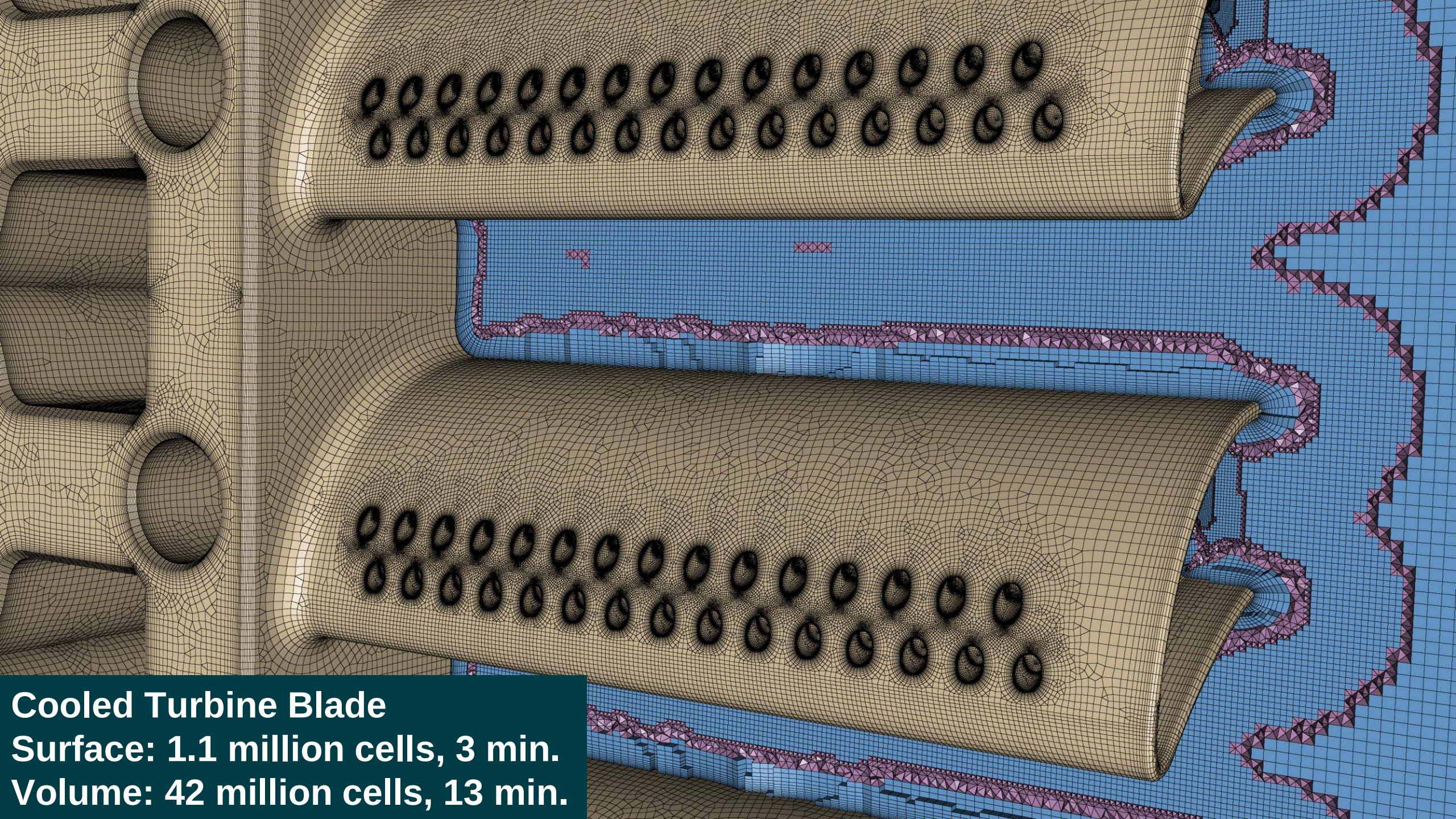






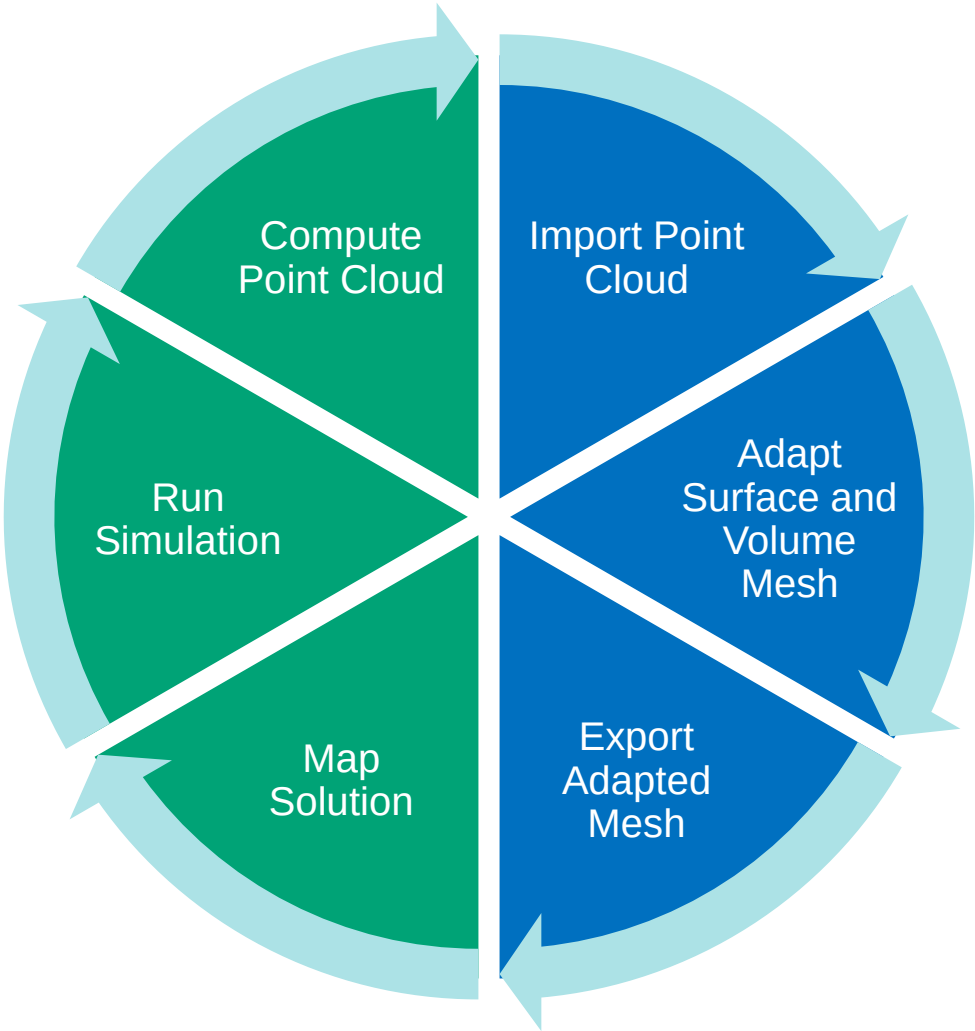

DrivAer
Surface: 1.1 million cells, 6 min.
Volume: 72 million cells, 24 min.


Extra 300
Surface: 60k cells, 20 sec.
Volume: 11 million cells, 7 min.


Cooled Turbine Blade
Surface: 1.1 million cells, 3 min.
Volume: 42 million cells, 13 min.

Adaptation

CFD Solver



Pointwise

Why Re-Mesh for Adaptation?

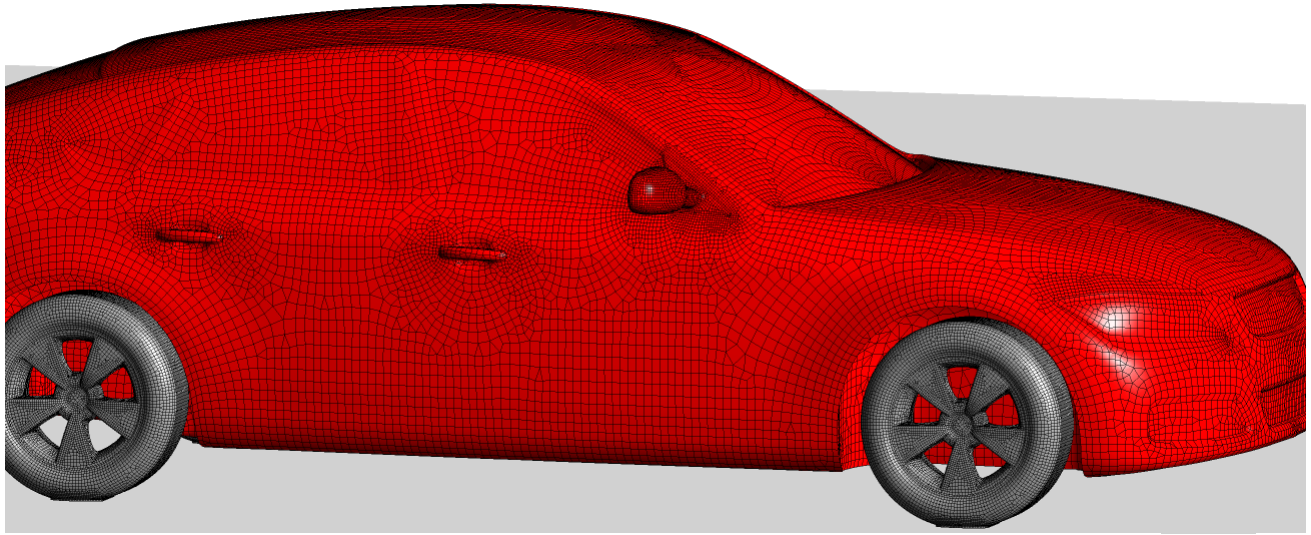
Fixed-mesh best-practice utilizes high-quality quasi-structured meshing for geometry and solution resolution

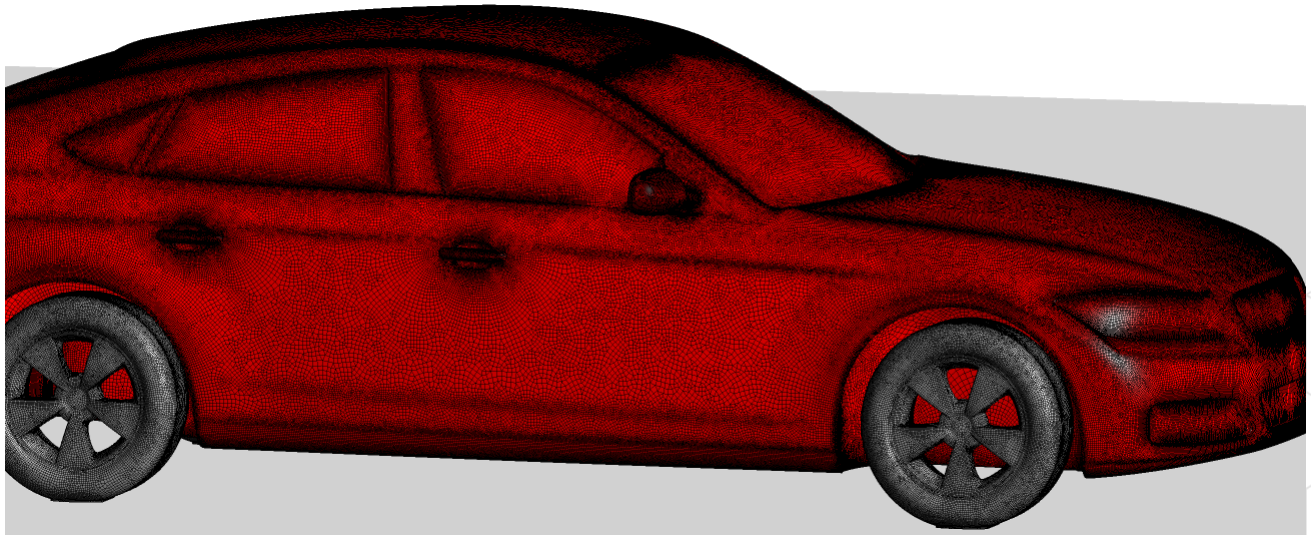
Re-meshing allows us to continue use of quasi-structured meshing where appropriate

Maintain geometry associativity

Achieve multiple objectives for the mesh while maintaining element quality

Automatic once initial mesh is created



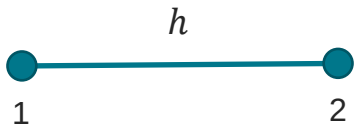


Discretization Error

$$\phi(x+h) = \underbrace{\phi(x) + \frac{\partial \phi}{\partial x}(x)h}_{\textit{supported}} + \underbrace{\frac{\partial^2 \phi}{\partial x^2}(x)h^2 + \cdots}_{\textit{truncated}}$$

Taylor series expansion of variation about x
Infinite series is continuous,
Truncated series is a discrete approximation

Discretization error can be controlled by reducing truncation error



Discrete solution on mesh h connecting DOF *1-2*

$$\phi^L\left(\frac{h}{2}\right) = \frac{1}{2}(\phi_1 + \phi_2)$$

Linear interpolation of discrete solution

$$\phi^H\left(\frac{h}{2}\right) = \frac{1}{2}(\phi_1 + \phi_2) + \frac{h}{8}\left[\frac{\partial \phi}{\partial x}_2 - \frac{\partial \phi}{\partial x}_1\right]$$

Cubic interpolation of discrete solution

$$\varepsilon\left(\frac{h}{2}\right) = |\phi^L - \phi^H| = \frac{h}{8}\left|\left[\frac{\partial \phi}{\partial x}_2 - \frac{\partial \phi}{\partial x}_1\right]\right|$$

Leading truncation error estimate

Adaptation Sensor

Requirements

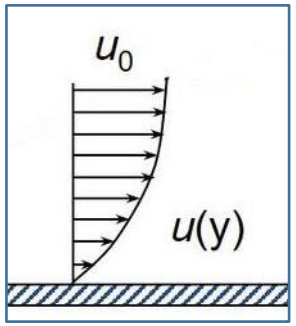
- Proportional to interpolation error (stability)
- Preserve boundary layer anisotropic mesh (near-wall physics model)
- Smooth size field (solver convergence)

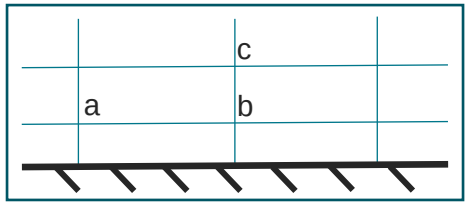
$$\varepsilon\left(\frac{h}{2}\right) = \frac{\vec{h}}{8}\left[\overrightarrow{\frac{\partial\phi}{\partial x_2}} - \overrightarrow{\frac{\partial\phi}{\partial x_1}}\right] = \mathrm{T}$$

- Anisotropic tensor

$$S \propto |\vec{h}|\left|\left[\overrightarrow{\frac{\partial\phi}{\partial x_2}} - \overrightarrow{\frac{\partial\phi}{\partial x_1}}\right]\right|$$

- No boundary layer protection





$$S \propto |\vec{h}|\left|\left[\hat{\vec{h}} \cdot \overrightarrow{\frac{\partial\phi}{\partial x_2}} - \hat{\vec{h}} \cdot \overrightarrow{\frac{\partial\phi}{\partial x_1}}\right]\right|$$

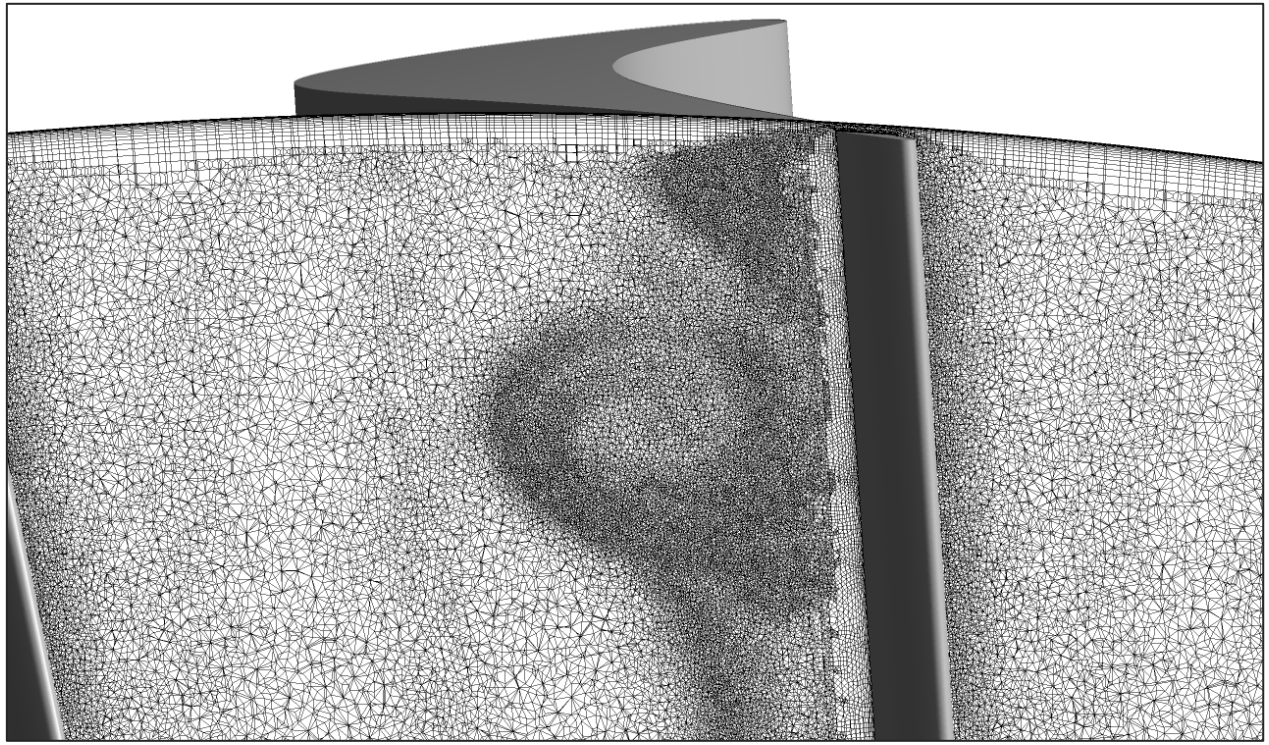
- No protection for solution discontinuity

$$S = K\,|\vec{h}|^p\left|\left[\hat{\vec{h}} \cdot \overrightarrow{\frac{\partial\phi}{\partial x_2}} - \hat{\vec{h}} \cdot \overrightarrow{\frac{\partial\phi}{\partial x_1}}\right]\right|$$

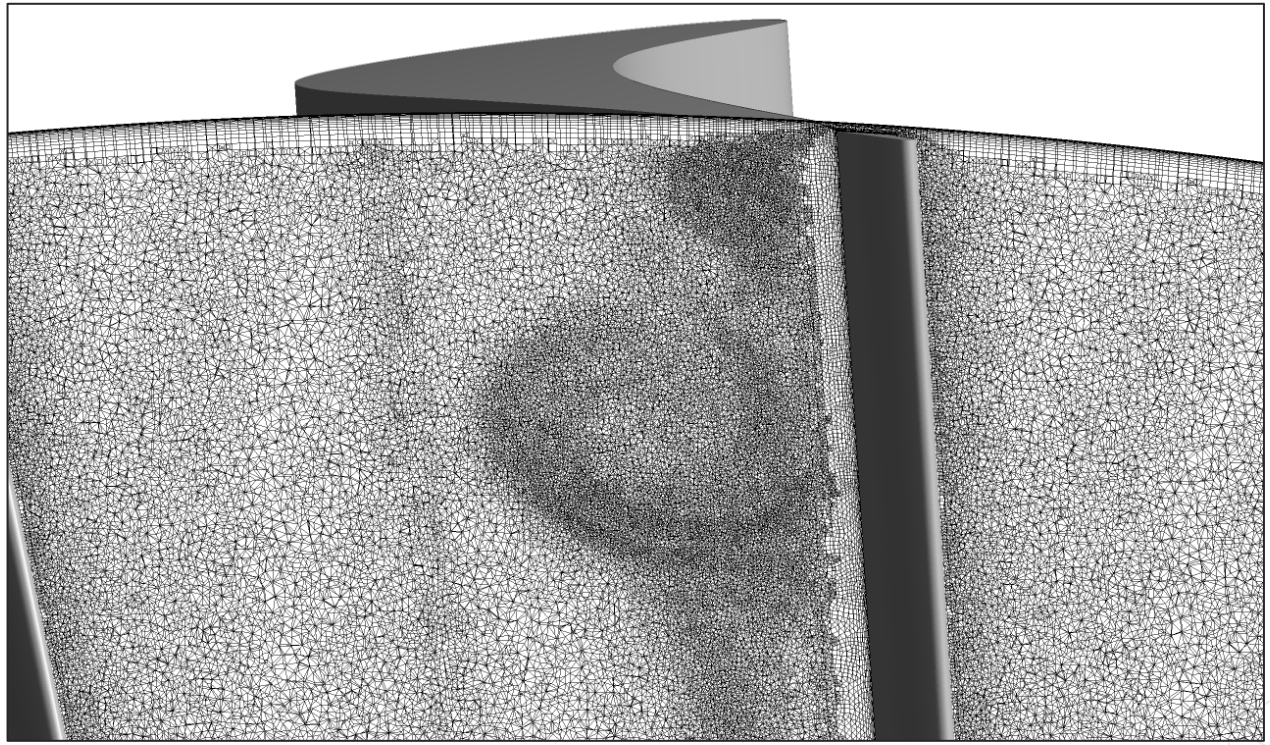
- Emphasis on larger than average edges (typically $2 < p < 4$)

Adaptation "p" Control

$$S = h^{\boldsymbol{p}} \left| \hat{\vec{h}} \cdot \left(\frac{\overrightarrow{\partial \phi}}{\partial x_2} - \frac{\overrightarrow{\partial \phi}}{\partial x_1} \right) \right|$$



$p = 2.5$



$p = 4.0$

Adaptation Mesh Size Control

Adapt where $S > S_{Thresh}$

- $h_{Target} = |\vec{h}| \sqrt[p]{\frac{S_{Thresh}}{S}}$ → point cloud

Continuous Mesh Complexity[1]

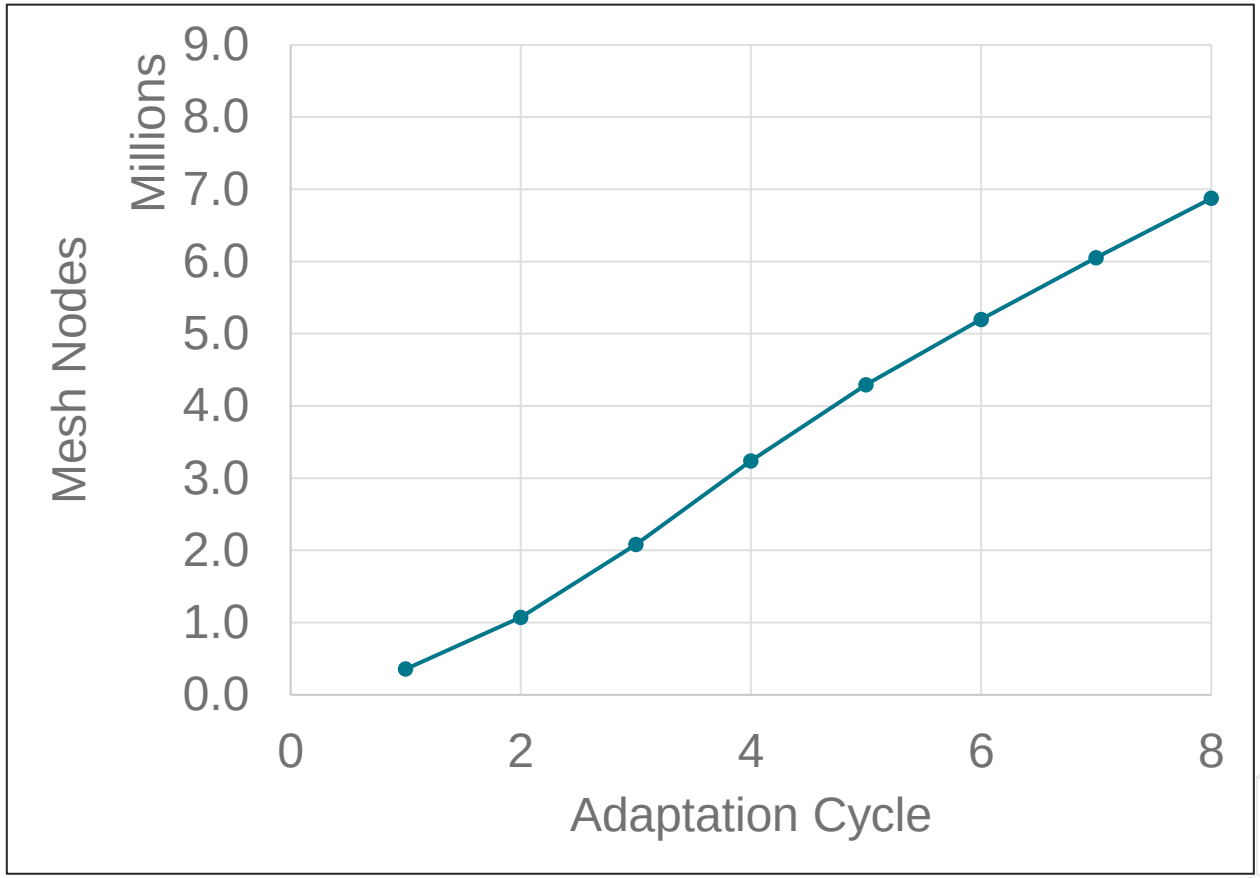
$$C(\mathcal{M}) = \int_{\Omega} \sqrt{\det(\mathcal{M})}\, d\Omega$$

- Correlates with number of nodes in the conformal mesh
- Discrete complexity:

$$C_{Current} = \sum_{i=1}^{N} \left(\frac{1}{{h_i}^3}\right) V_i \quad \text{using } h_{Current}$$

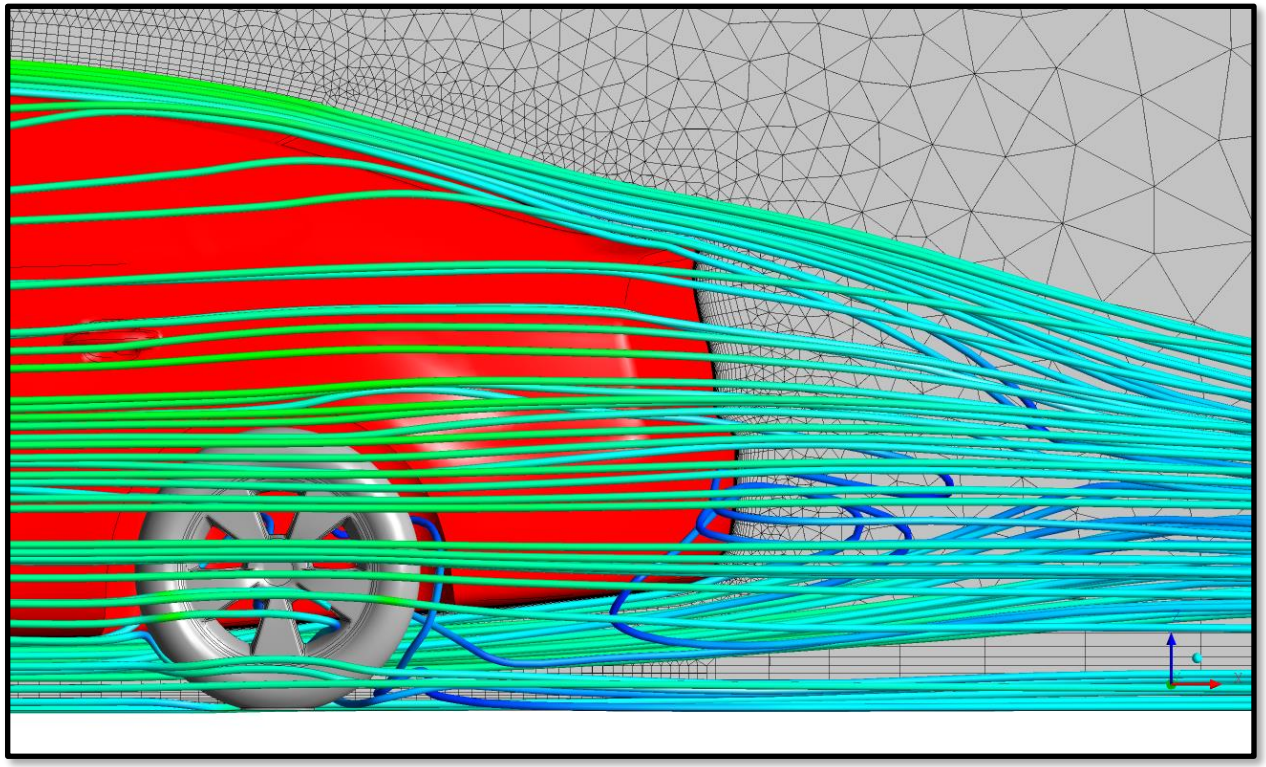
$$C_{Adapt} = \sum_{i=1}^{N} \left(\frac{1}{{h_i}^3}\right) V_i \quad \text{using } h_{Target}$$

Find S_{Thresh} such that $C_{Adapt}/C_{Current}$ matches adaptation growth rate (e.g. 1.3)

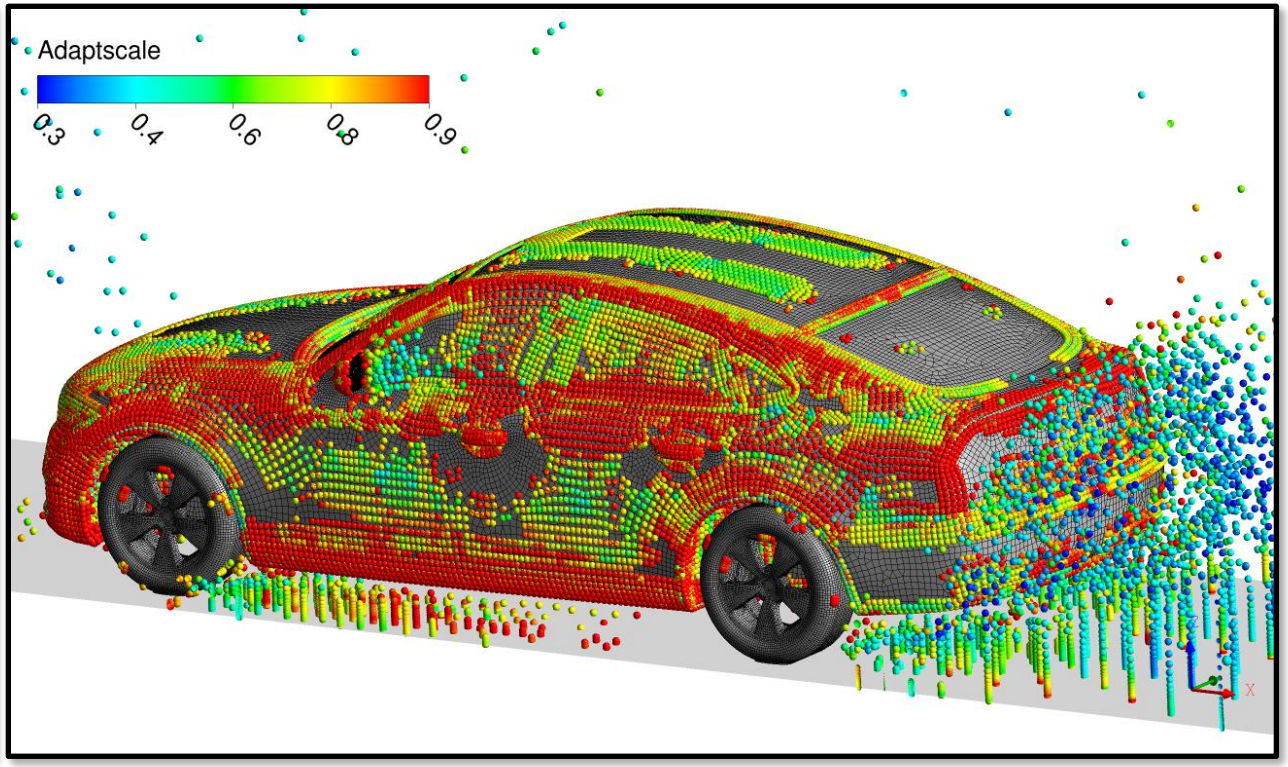


[1]Loseille, A. and Alauzet, F., "Continuous Mesh Framework Part I: Well-Posed Continuous Interpolation Error," SIAM Journal on Numerical Analysis

DrivAer Fastback Model, TUM

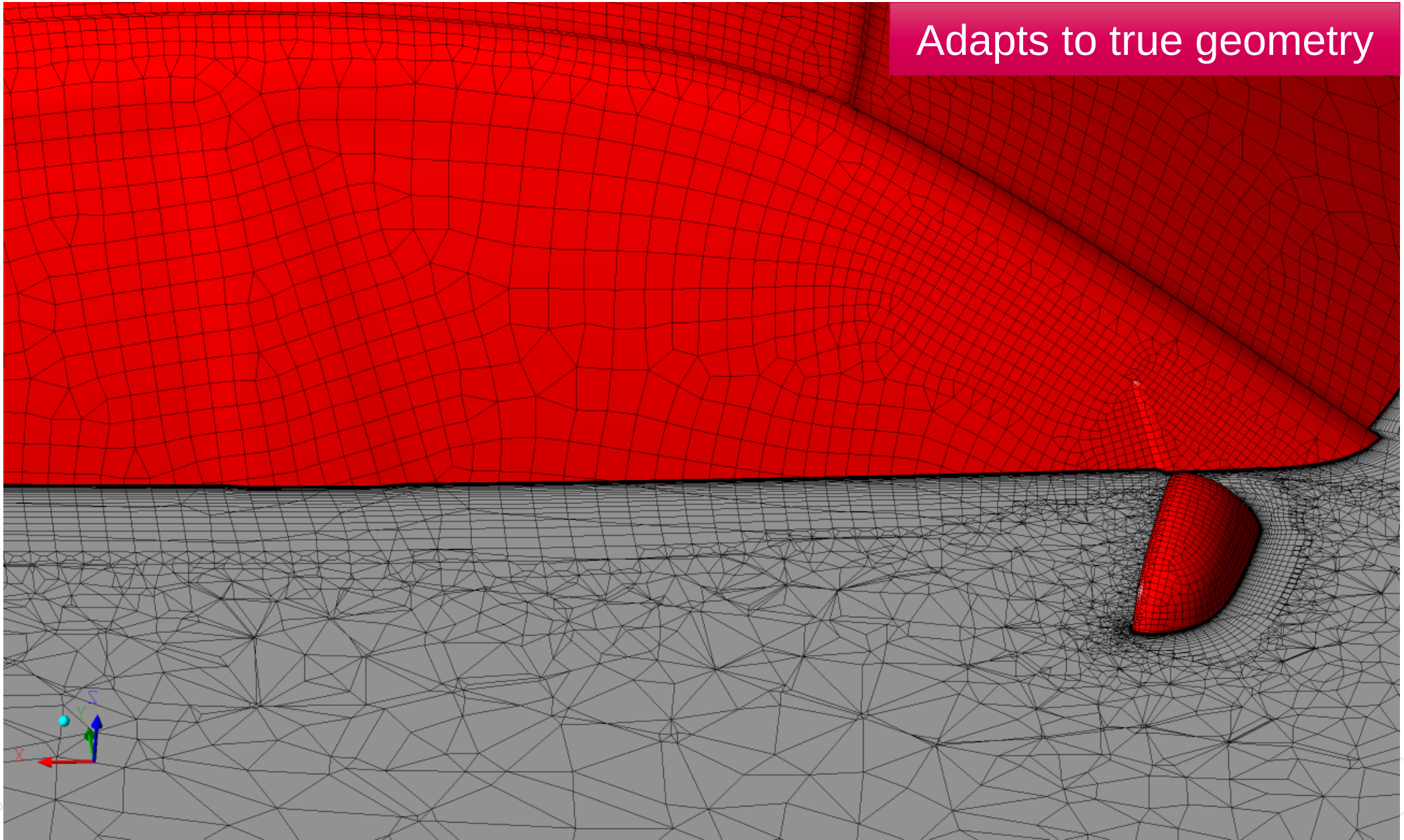


Baseline Mesh + Solution

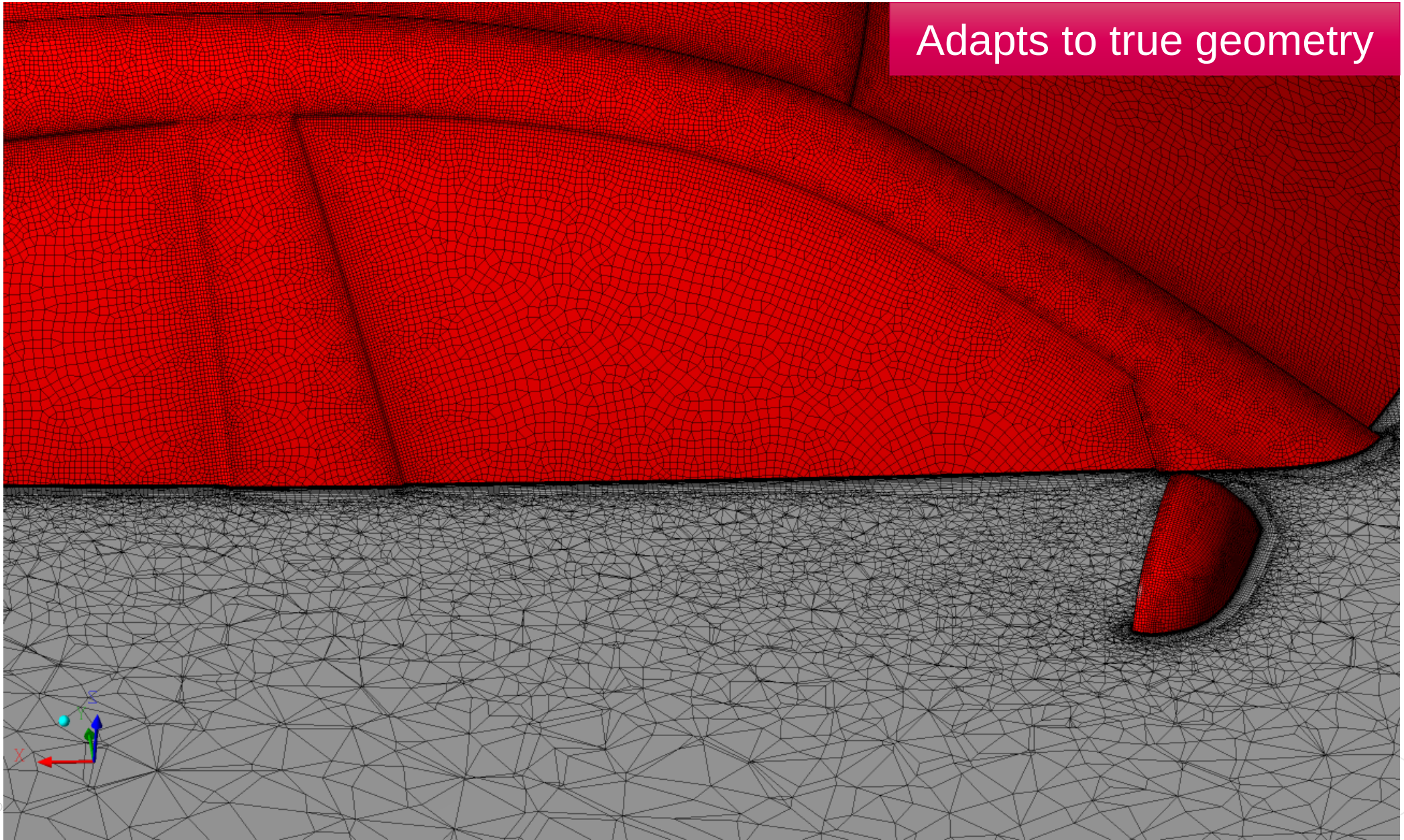


Sparse Adaptation Point Cloud

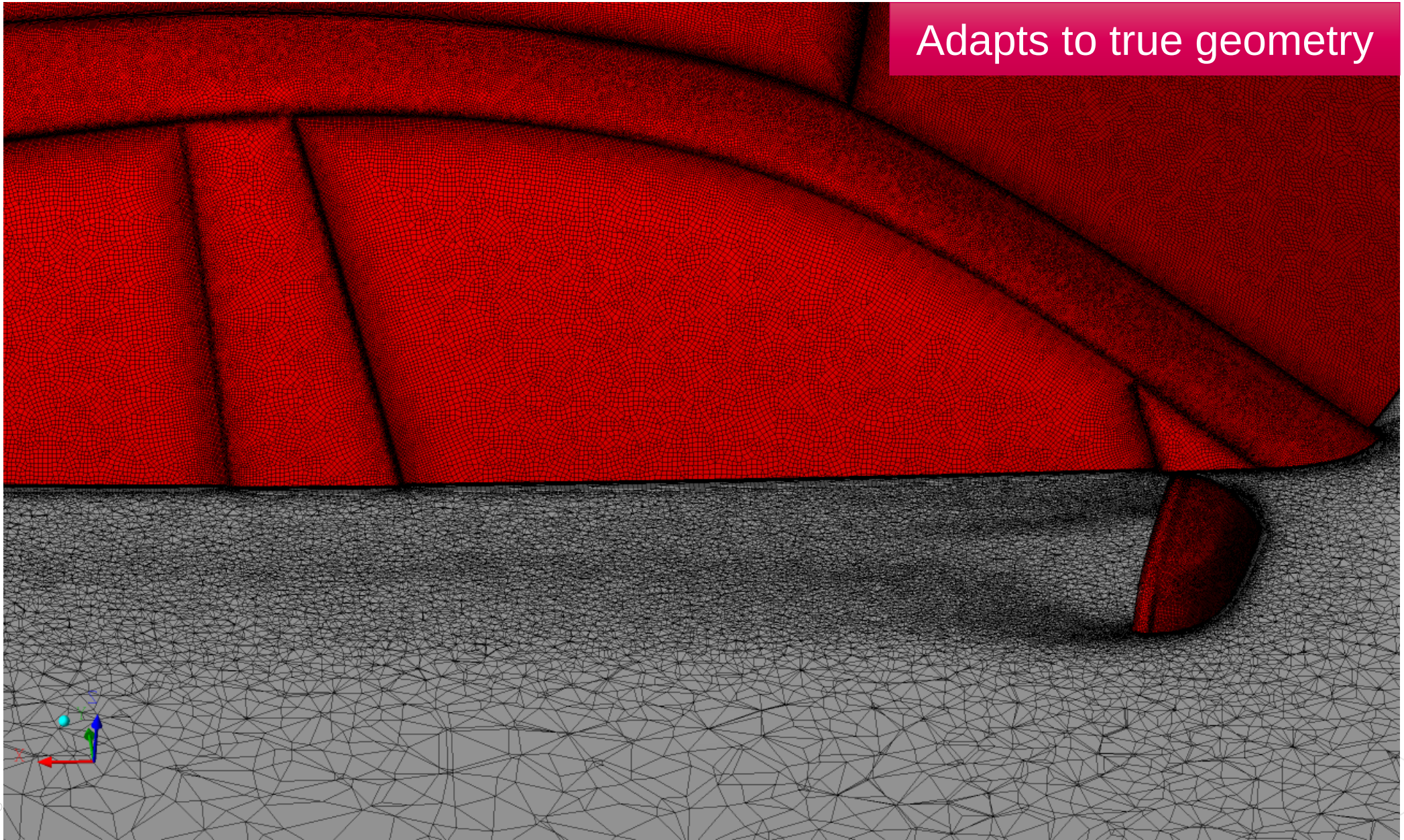
Baseline Mesh



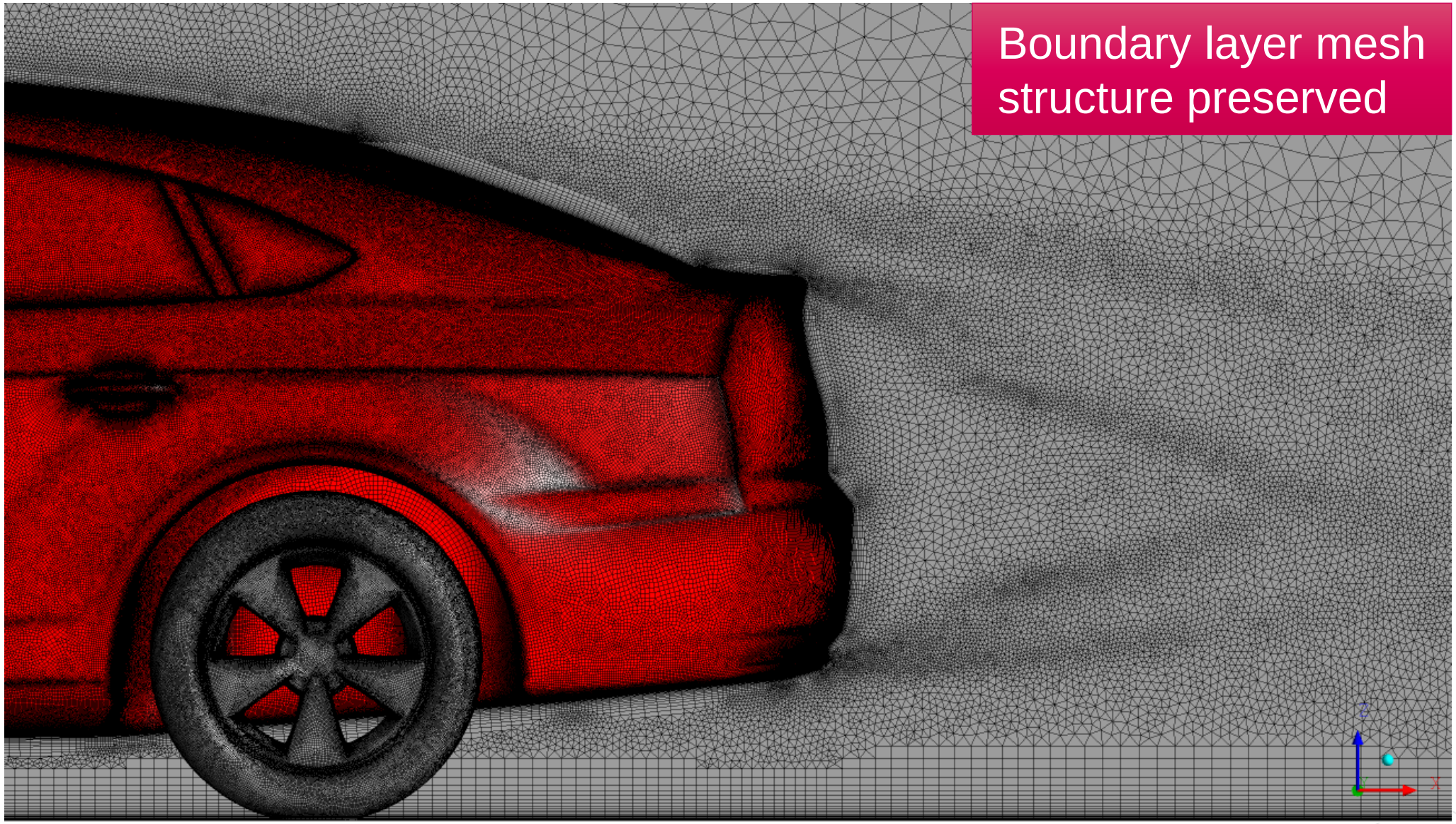
Mesh Cycle-5

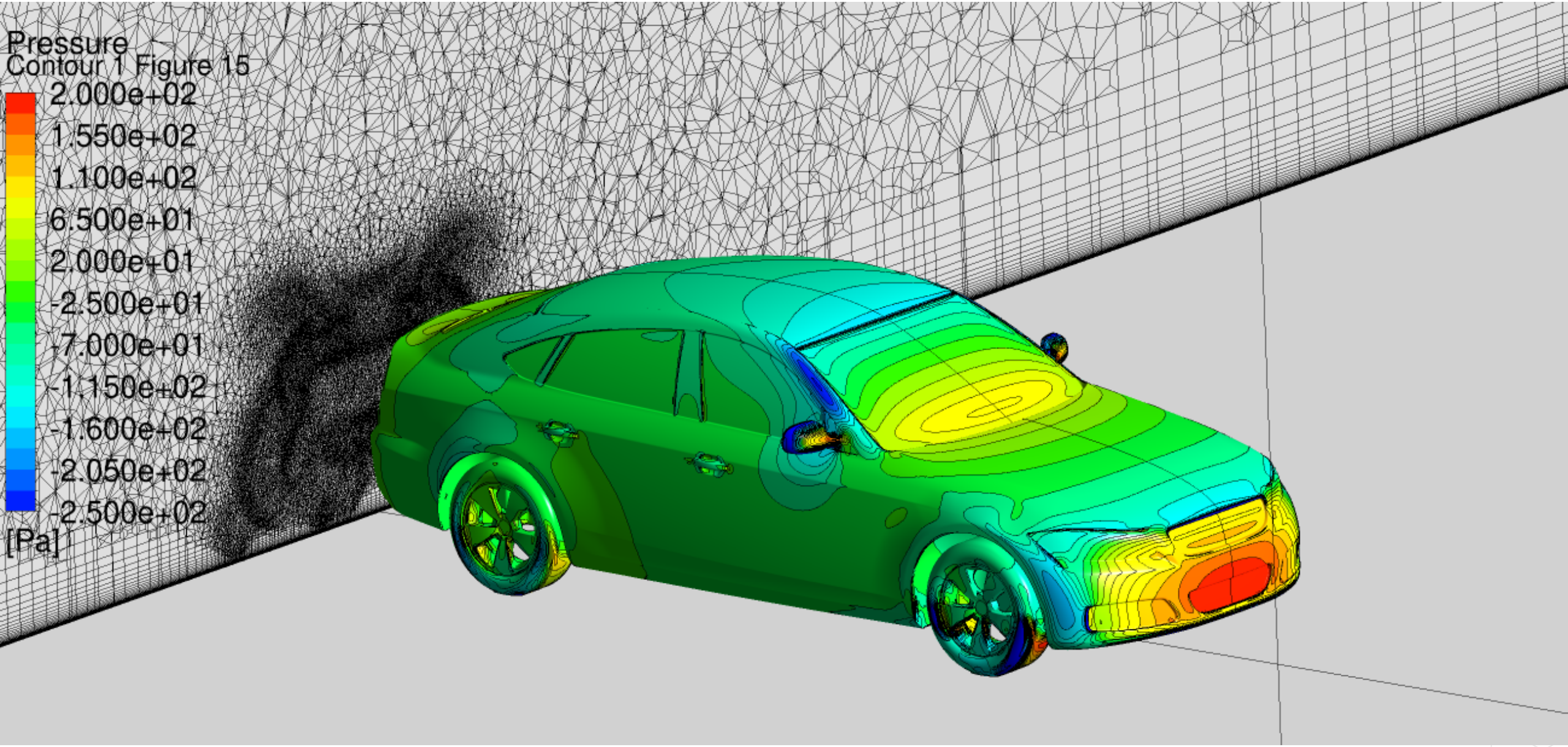


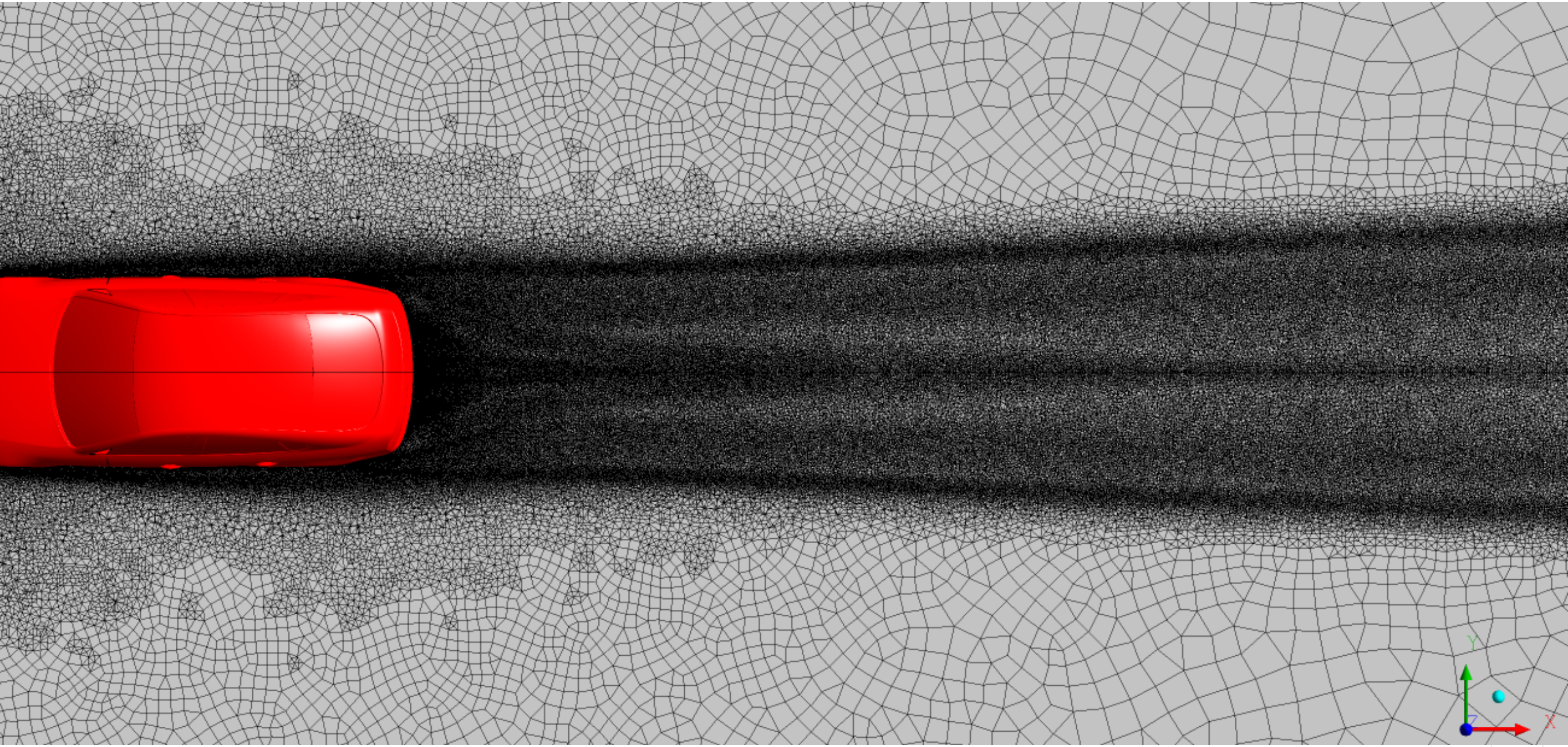
Converged Mesh

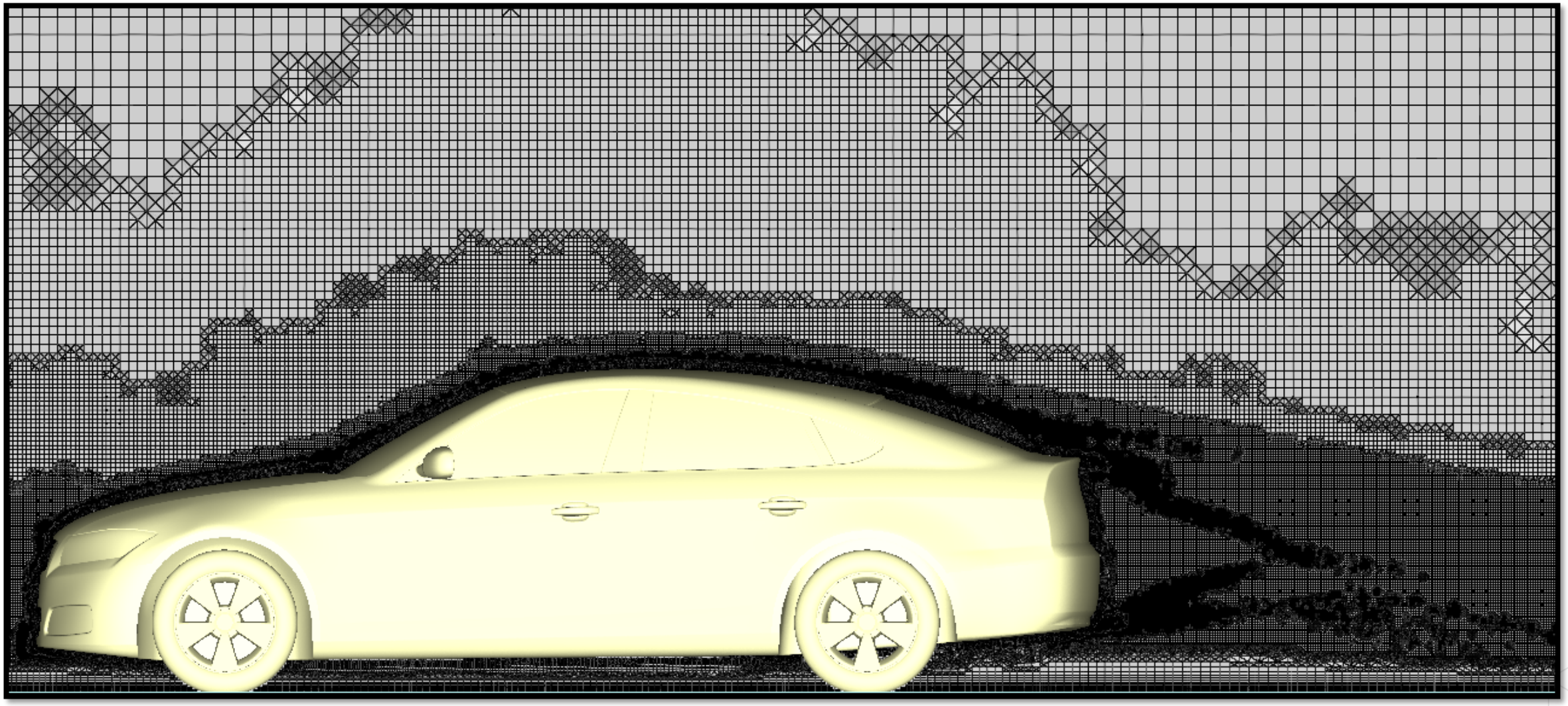


Converged Mesh

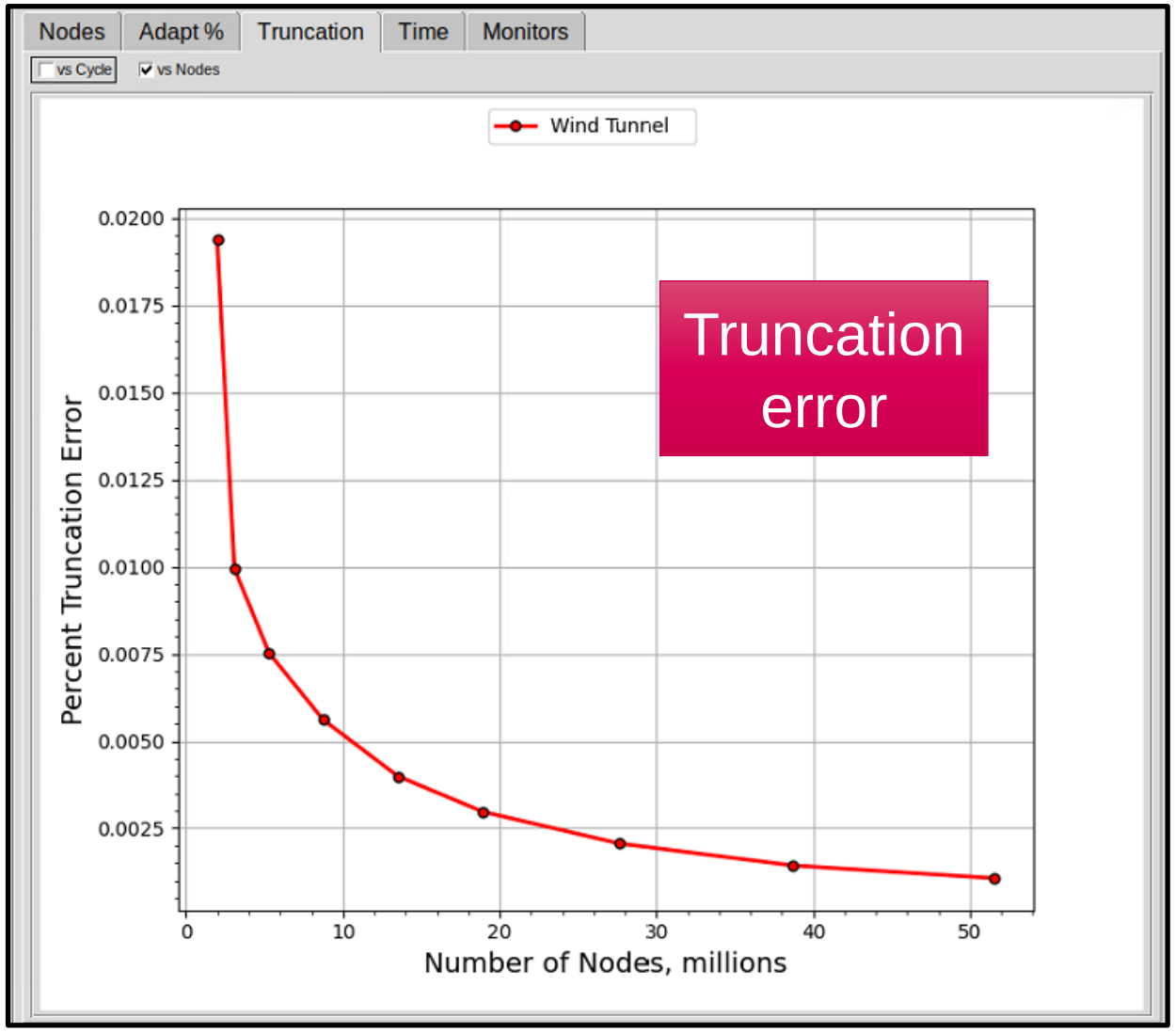


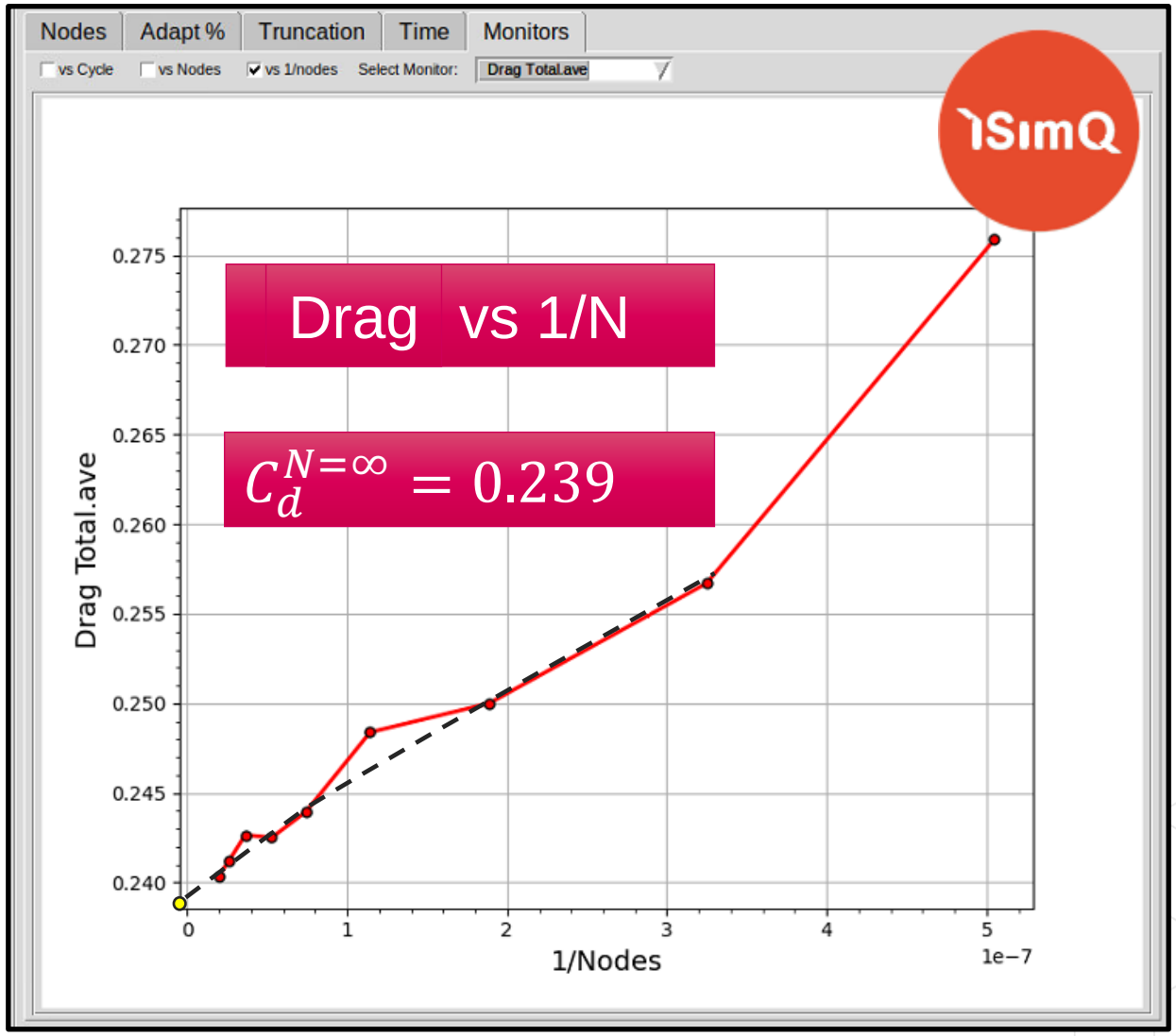






Truncation Error and Total Drag vs Adapted Mesh



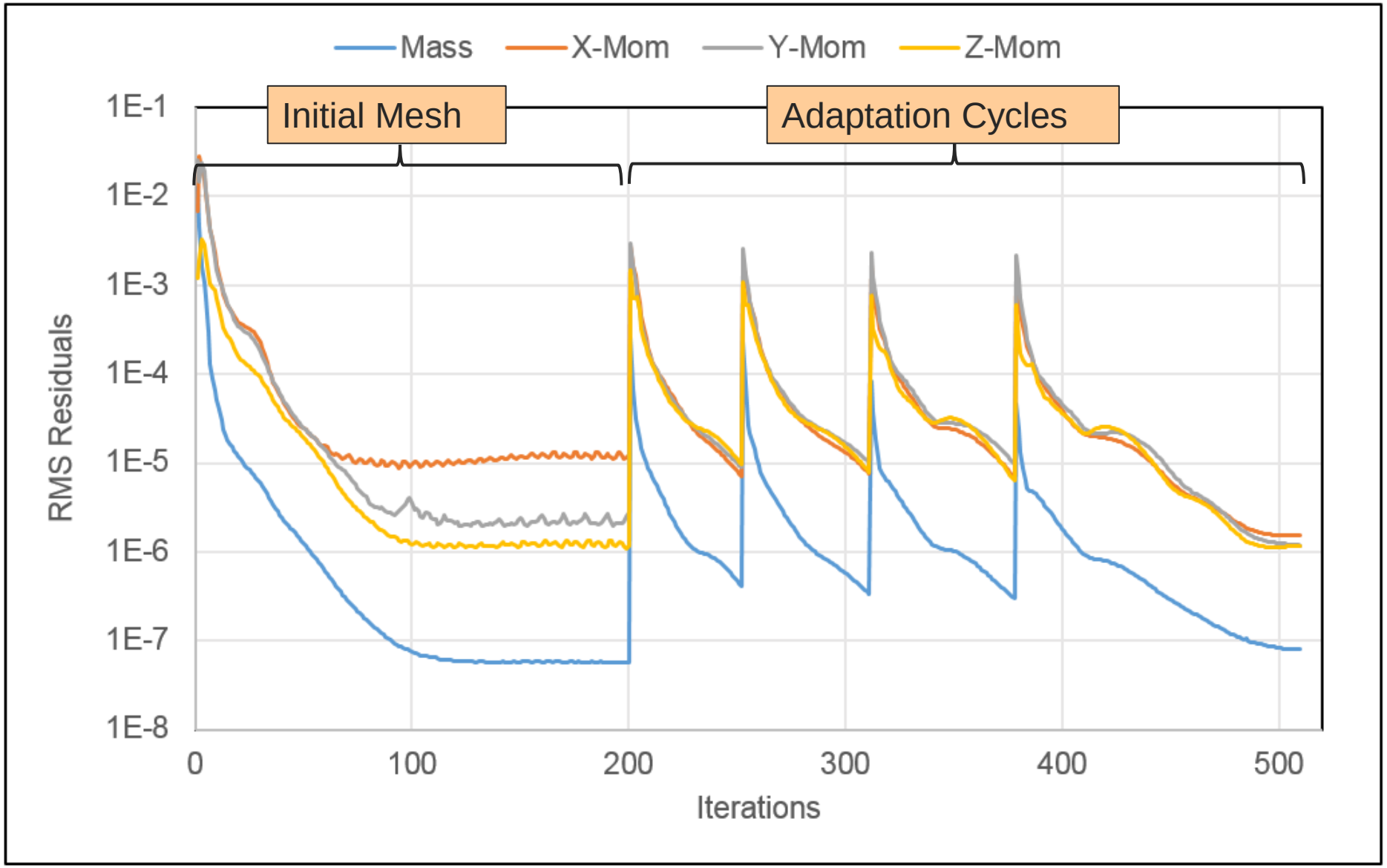


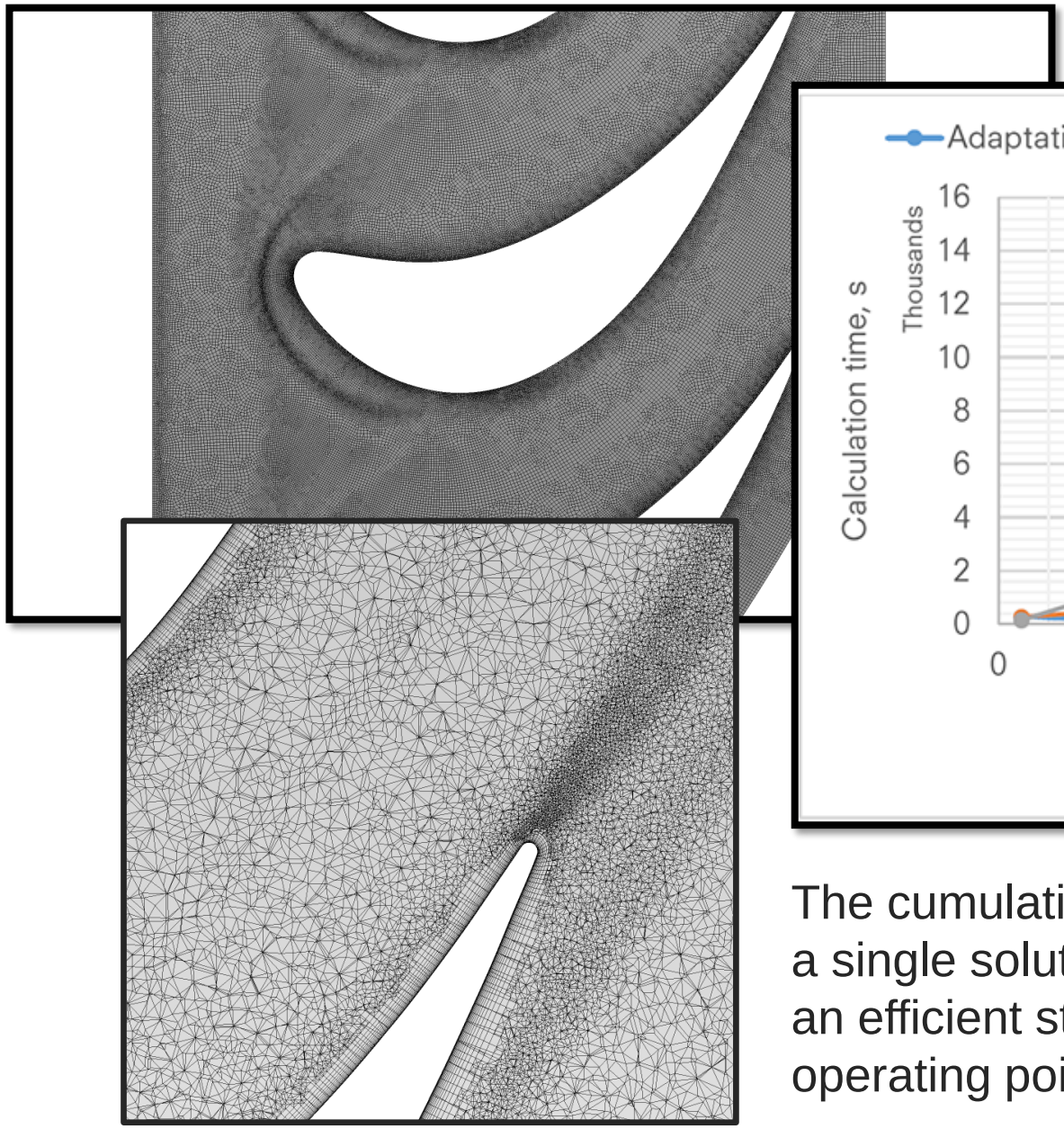
Cd Results for Fastback Car

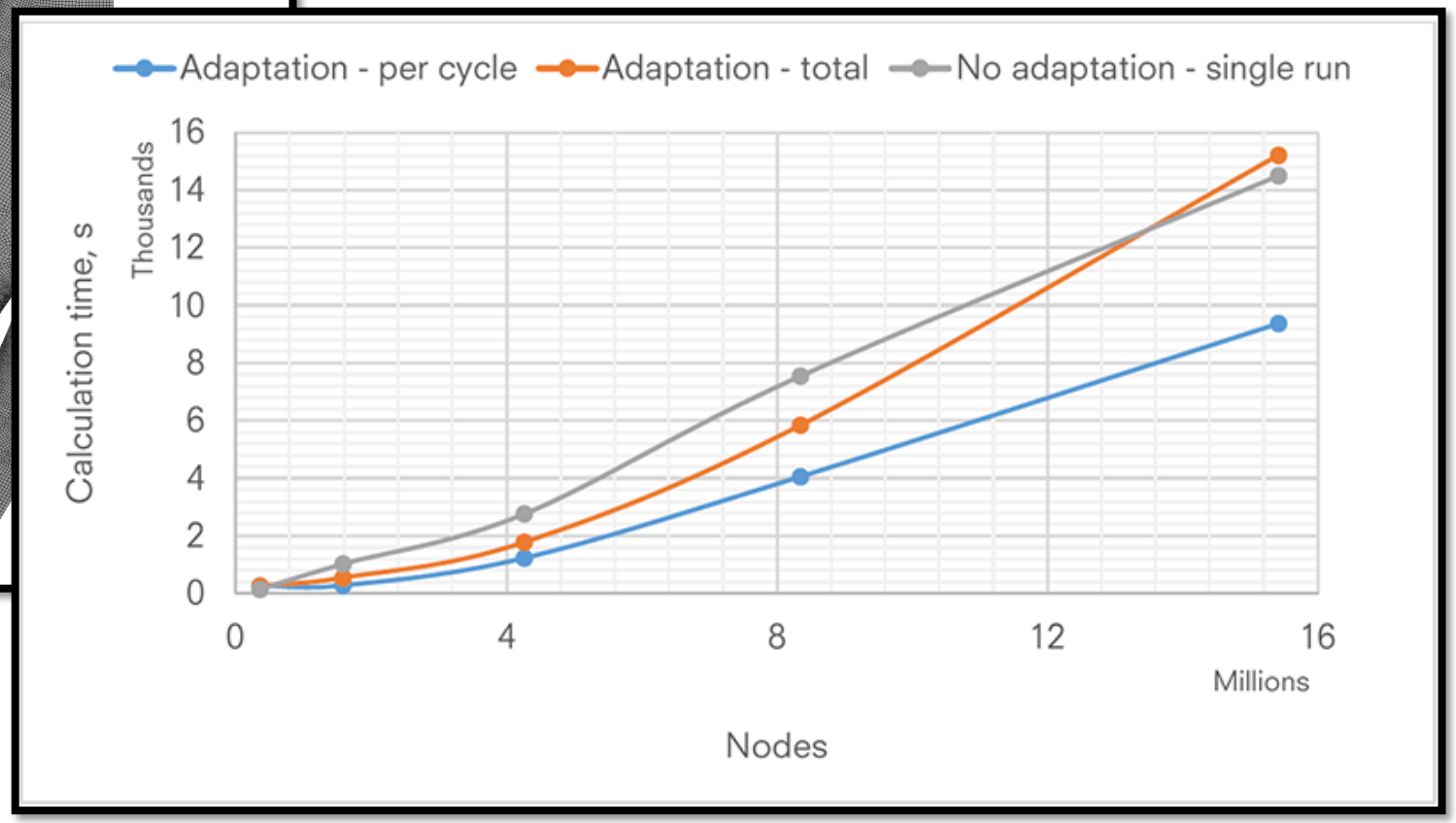
Surface	Exp. Data	Adapt $N = \infty$	Adapt % Error	Soares[1]	Soares[1] % Error
Body	n.a.	0.163		0.170	
Mirrors	n.a.	0.011		0.010	
Wheels	0.063	0.065	+0.8%	0.052	-4.4%
Total	**0.251**	**0.239**	**-4.8%**	**0.232**	**-7.6%**

[1]Soares, R.F., Garry, K.P., Holt, J., "Comparison of the far-field aerodynamic wake development for three DrivAer Model configurations using a cost-effective RANS simulation", SAE World Congress Experience, 4 - 6 April 2017, Detroit, Michigan, USA

Solver Convergence

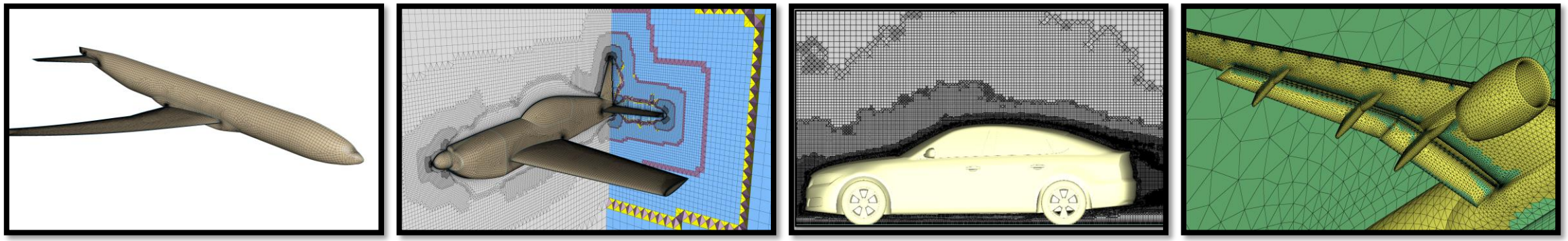






The cumulative time for all adaptation cycles is equivalent to a single solution on a best practice mesh making adaptation an efficient strategy for automatically resolving multiple operating points.

Thank You!



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